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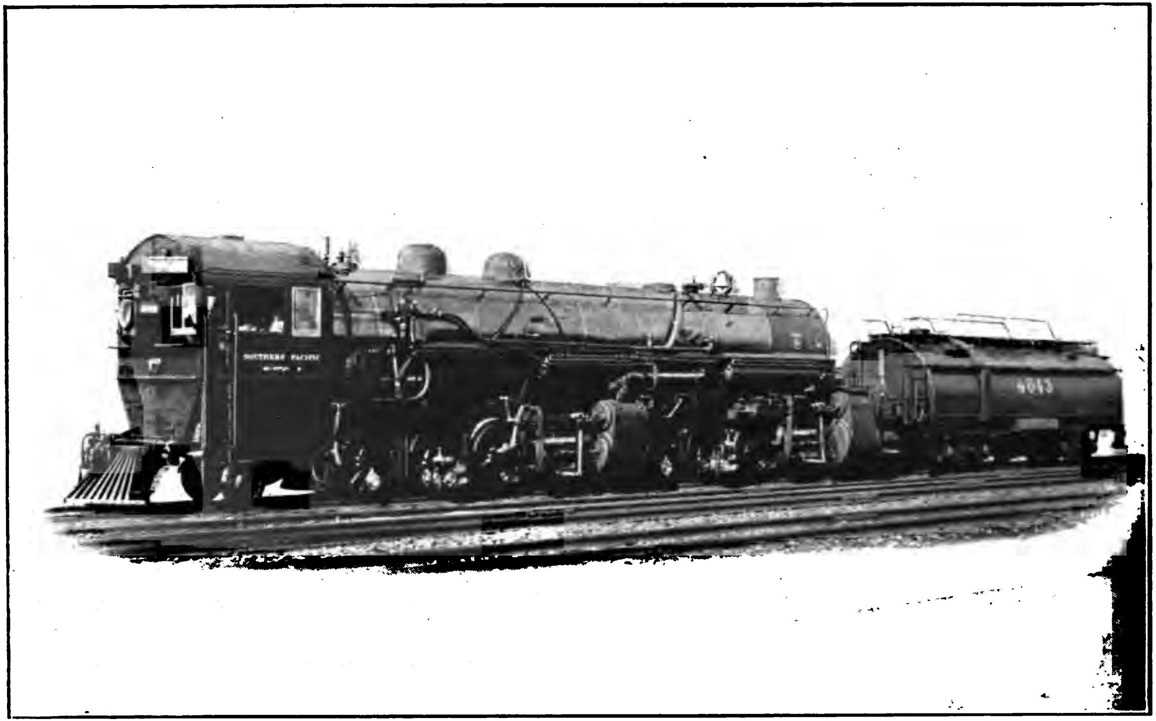
OIL FUEL EQUIPMENT FOR LOCOMOTIVES



Mallet Articulated Compound Oil-fired Locomotive, Southern Pacific Railway, U.S.A.

(By the courtesy of the Anglo-Mexican Petroleum Co., Ltd.)

OIL FUEL EQUIPMENT FOR LOCOMOTIVES

AND

PRINCIPLES OF APPLICATION

BY

ALFRED H. GIBBINGS

A.M.INST.C.E.

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PREFACE

THIS little publication is intended chiefly for the use of locomotive superintendents and others who have the control of railway engines using oil as fuel. It is entirely of a practical character, and the few references to theory and principles of combustion are necessary in order that the subject may be clearly understood. Those who wish to study the historical, theoretical and chemical sides must have recourse to the many scientific text-books on Petroleum and Oil Fuel.

Also with regard to the examples and descriptions given of oil-burning apparatus, they must be accepted as typical only of possibly half a hundred similar classes on the market. The intention has not been to describe in detail any particular make of atomiser, but those referred to have been selected as illustrative of the principles embodied in the three oil-burning systems.

Some specification clauses for the use of those desirous of obtaining offers for the supply of oil-burning equipments have been included.

A. H. G.

BALCARCE 278,
BUENOS AIRES,
REPUBLICA ARGENTINA,
March, 1915.

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SECTION I

PRELIMINARY OBSERVATIONS AND DATA

During the last few years there has been a very great development in the sources of supply of crude petroleum in all parts of the world. This has resulted in increased facilities of transport of the oil, and hence the use of liquid fuel in place of coal or wood is now a commercial possibility in many countries. Among the countries in which this crude petroleum or "fuel oil" is found are—Canada, California, Texas and Mexico in North America, Peru, Venezuela, Colombia, the Argentine (Comodoro Rivadavia oilfields) in South America, in various parts of Russia, Borneo, Java, Trinidad, etc.

One of the earliest applications of crude petroleum as a fuel was on locomotives. This was quite natural, as the railways in the vicinity of oilfields would avail themselves of such an abundant and cheap fuel.

In point of fact the facilities in the way of unlimited supplies of oil at a purely nominal cost have tended to keep back the scientific development of locomotive oil-burning apparatus rather than to encourage its careful study. For this reason oil has been used on locomotives for many years with very rude and primitive appliances, and the perfection to which the equipment has now been brought has been due in a great measure to the experiments which have been made in countries into which oil has had to be imported.

This has been especially the case in England, where the cost of fuel oil is high and the cost of coal comparatively low,

and thus the incentive has existed to obtain the best possible results from the calorific value of the oil. In other countries where neither coal nor oil is found, and where all classes of fuel have to be imported, the necessity of obtaining the most efficient apparatus is quite apparent.

The following are the principal railways using oil fuel more or less extensively, viz. :—Baltimore and Ohio, Southern Pacific Railway, and Pacific Railway in the United States of America; Austrian State Railways; Western Railway of France; Paris, Lyons, and Mediterranean Railway; Paris and Orleans Railway; Roumanian State Railways; South Russian Railways; Shin-Yetsu Railway, Japan; Los Angeles Railway; Tehuantepec National Railway; Mexican National Railway; Interoceanic Railway of Mexico; Peru Railway; Chilian Railway; Central Railway of Brazil; San Paulo and Paulista Railways; Buenos Aires and Pacific Railway; Taltal Railway; on some of the South African Railways; and on the Great Eastern Railway, England.

The class of oil used on the respective railways as liquid fuel varies considerably as regards chemical composition, viscosity, flash point, percentages of sulphur and water, etc., according to the locality in which it is found and also as to whether it is a crude oil or a bye-product of distillation.

Crude oil, by which is meant the natural product as found in the wells, differs from that sold as fuel oil, the process known as "topping" or first distillation being applied to remove the lighter oils, such as the petrols and kerosenes, for the higher market value which they possess.

Crude oil is lighter in viscosity and usually has a low flash point. Oil fuel is heavy, dark in colour, and viscous. Other hydrocarbons, such as coal-tar, creosote, blast furnace oil, water-gas tar, astatki, and other residua, may be used as fuel, burning under similar conditions to those of oil fuel, adjustments being made in the burners and furnaces to give complete combustion.

From the locomotive engineer's standpoint it will suffice to consider here only those oils being sold commercially

as fuel oil, and under the aspects only which affect their steam-raising qualities. His chief concern, after the question of supply, is how to get the highest evaporative results from a given calorific value, and hence the composition and specification of the oil is the first consideration.

The Composition of commercial fuel oils is given in Table 1. The greatest divergence from a generally even average is in the percentage of sulphur. The effect of sulphur is to slightly lower the total calorific value, the number of B.Th.U. per pound of sulphur being 4,500 only.

TABLE 1.—COMPOSITION AND CALORIFIC VALUES OF FUEL OILS.

Class of Oil.	A Carbon (per cent.).	B Hydrogen (per cent.).	C Sulphur (per cent.).	D B.Th.Units (per lb.).
Mexican	83·52	11·68	3·27	18,900
Texas	86·30	12·22	1·33	18,400
Russian	84·94	13·96	0·10	18,611
Burmah	86·40	12·10	0·50	18,864
Borneo	87·80	10·78	0·03	18,831
Galician	85·30	12·60	0·10	18,009
Comodoro Rivadavia	84·50	13·80	0·37	19,130
Roumanian	87·11	11·87	0·16	19,320
Californian	84·43	10·99	0·59	18,806

N.B.—These oils also contain a small percentage of oxygen and nitrogen.

In this connection the Anglo-Mexican Petroleum Products Co., Ltd., say: "In the past some prejudice has existed against an oil containing more than 0·75 per cent. of sulphur, although no scientific reason can be given for fixing this or any other arbitrary figure. No objection, however, is made to the presence of sulphur in coal, nor any record of deterioration of boilers on this account. It is significant that the amount of coal of average quality required to give an equivalent heating value to a pound of oil would contain more sulphur than is contained in

1 pound of Mexican oil. The extensive experience with oil burning which is now available shows that boiler corrosion does not take place. The only point that need be mentioned in this connection is that it is advisable when steel chimneys are used that the temperature of the flue gases should not fall below 400° F., a contingency which rarely arises in actual practice. The fact that the British Admiralty have, after careful investigation, raised the percentage in their specifications from the conventional standard of 0·75 per cent. to 3 per cent. reflects the altered views on this question."

No mention is made in Table 1 of the presence of water, because water does not form a component of oil. Nevertheless, water is often present with the oil when sold commercially, and is so intimately mixed with the particles of oil that its detection is not possible until the oil has been at rest for a considerable time, and not fully then unless heated. Under the pressure system of burning liquid fuel its presence, but not its quantity, is immediately detected in the nature of the flame, but with the steam-jet burner it may pass over into the furnace without evidence of its presence. Water in oil cannot be other than detrimental to combustion and efficiency, and its actual effect in the furnace will be considered later, but in any case it should not be paid for as oil fuel. Samples should therefore be frequently taken from oil deposit tanks and the quantity of water noted after natural separation by standing. Specifications for purchasing fuel oil should contain a condition allowing for rebate on price according to the quantity of water the oil may be found to contain. Outside its deleterious effect on combustion the presence of water vapour in the firebox of a locomotive produces chemical compounds with any sulphur present in the oil, and these may attack the side and crown plates in time. Hence water should be entirely eliminated. Owing to the rapid expansion coefficient of petroleum, the water will gravitate out by heating the oil, and the degree of heat applied need not be so high as to vaporise the water. This is one of the reasons for fitting heating coils in oil tanks.

The Calorific Values of the several classes of fuel oils are given in Table 1. A fair average may be taken as 18,800 B.Th.U. per pound. Coal contains from 9,000 to 14,500 B.Th.U. per pound, and hence the heating value of oil is from 30 to 100 per cent. greater weight for weight. In the case of coal combustion much more latent heat is absorbed in the chemical combinations of combustion than with oil, and the percentage of ash may be as high as 5 per cent. It follows, therefore, that on a weight for weight basis only, and exclusive of other efficiencies which oil fuel possesses, the direct comparison between the two on a thermal unit basis is not conclusive.

The thermal efficiency of oil furnaces is about 80 per cent. and coal firing about 65 per cent., a difference in favour of oil over and above its percentage higher calorific value, arising from more perfect combustion, less excess air factor, and greater heating surface exposed to the flame. This comparison should really be stated in terms of unit weight and time, the time representing the exact period of full evaporation of water. The true economical aspect depends also, and very largely, on factors outside of test conditions, such as losses arising with coal from banked fires, inferior stoking, dirty heating surfaces, incomplete water circulation, and many other such items.

These points are mentioned here to show that a direct comparison between oil and coal or any other fuel on the thermal unit basis is very misleading as to comparative heat values, even theoretically, the real ratio more often being as 2 : 1. This is of course a greatly varying factor, as coal varies so much in calorific value and composition, while oil fuel is nearly constant.

The calorific value of any fuel can be determined by calculation when once its analysis is known. The principal constituents of fuel oil are carbon, hydrogen and sulphur. Their calorific values are respectively :—

Carbon . .	14,646	B.Th.U.	per pound.
Hydrogen . .	62,100	,,	,,
Sulphur . .	4,500	,,	,,

Mexican fuel oil has a percentage composition of :—

Carbon	83·52 per cent.
Hydrogen	11·68 ,,
Sulphur	3·27 ,,
Incombustibles . . .	1·53 ,,
	100·00 ,,

The formula for obtaining the calorific value is as follows : Multiply the calorific value of each element by its percentage in the oil, add all the products together and divide by 100.

Thus :—

$$\frac{(83{\cdot}52 \times 14{,}646) + (11{\cdot}68 \times 62{,}100) + (3{\cdot}27 \times 4{,}500) + 1{\cdot}53}{100}$$

equals 19,648 B.Th.U. per pound.

The heat of formation of the compound has not been taken into consideration in the foregoing formula, and therefore the figure is a little above the actual value.

The usual, and more satisfactory, method is to determine the calorific value by testing the oil in a calorimeter, of which there are several types on the market.

Samples of oil consignments should be taken and the calorific value determined in this way.

The Viscosity or fluidity of an oil is determined by the rate of flow through a specific orifice under a certain head. The following Table 2 of viscosity of Mexican fuel oil at various temperatures will indicate the marked increase in fluidity that takes place as the temperature rises :—

TABLE 2.—VISCOSITY OF FUEL OIL.

Temperature.	Viscosity.
32° F. . . .	8,412 seconds
40° F. . . .	5,096 ,,
50° F. . . .	2,227 ,,
60° F. . . .	1,285 ,,
70° F. . . .	539 ,,
80° F. . . .	335 ,,
90° F. . . .	210 ,,
100° F. . . .	145 ,,
110° F. . . .	95 ,,

The above tests were taken by a viscometer designed by the late Sir Boverton Redwood, Bart., F.R.S.E., and this instrument is the one usually employed.

"The comparison is made on the basis of rape oil and the number of seconds is noted which 50 c.c. of oil takes to reach a predetermined mark at any desired temperature. This number is then multiplied by 100 and divided by 535 (the number of seconds for rape oil at 60° F.); the product is multiplied by the specific gravity of the oil and divided by 0·915 (the specific gravity of rape oil at 60° F.); the result gives the viscosity of the particular oil under test. The time occupied by the flow of 50 c.c. of water at 60° F. is 25·5 seconds" (Lewes).

The viscosity of liquid fuels at different temperatures has a most important bearing on the design of oil fuel apparatus and piping.

The Specific Gravity of fuel oil varies according to the district from which it comes. Its range is between 0·790 and 0·950, taking water as 1. In determining weights, therefore, it is necessary to know the specific gravity. Specific gravities are taken at 60° F., and at that temperature a working average figure of 0·85 may be used.

The Flash Point is the temperature at which any oil commences to give off inflammable vapour. For fuel oils the flash points vary from 80° F. to 300° F. The higher flash points are obtained by first distilling off the more volatile portions. The British Admiralty's specification was 270° F.; the Russian Navy requires 212° F., and in America the usual minimum is 200° F.

The question of flash point is more important as regards freedom from danger of ignition during transport or storage. It does not seriously affect the locomotive engineer in any other way, and provided ample ventilation is arranged and ordinary precautions adopted there is no objection to oils having a very low flash point.

Crude oils are now on the market having a flash point of 80° F., and are being used with perfect safety. They are cheaper than those to which the first process of distillation

or "topping" has been applied. In specifying for fuel oil it is necessary to state the flash point required.

General Advantages of Liquid Fuel for Locomotives.

The following is a list of the advantages generally experienced with the use of oil fuel on railways as compared with coal, and possibly local conditions may suggest others.

1. *Reduction in the Cost and Weight of Fuel.*—Data can be obtained on these points from the published returns of some of the railways mentioned in the previous pages. On the Mexican Railway in three years the whole of the locomotives were changed from exclusively coal burning to exclusively oil burning with reductions of nearly 40 per cent. in cost and 30 per cent. in weight.

2. *Saving in Cost of Handling.*—This is due to the smaller weight of oil required consequent on its higher calorific value. In many cases an engine will carry enough oil for a round trip. The number of storage depôts can be reduced. There is also the question of the wastage of coal in transhipment.

3. *Less Manual Labour in Stoking.*—This has also the advantage of leaving the fireman much more free and physically capable of assisting the engine-driver. There is also no danger of having dirty fires on a hard run.

4. *No Smoke, Ash or Clinker.*

5. *Adjustment of Fuel to Load.*—This can be effected instantaneously by valve operation only. With coal it is necessary to have a thick bed on the firebars, and this is largely wasted when duty is over.

6. *Cleanliness in Passenger Service.*—This is an exceedingly important matter on any roads, but particularly on some naturally dusty tracks. It is possible to lay the dust and improve the track by sprinkling heavy oil over it.

7. *Higher Evaporative Efficiency* due to more effective heating surface.

8. *Weathering of Coal.*—This loss, which ranges from 2 to 10 per cent., is eliminated. It is found that dry storage has no advantage over storage in the open, but in most

cases the losses appear to be practically complete at the end of five months.

9. *Elimination of Camp and Crop Fires.*—As there are no sparks from an oil-burning locomotive, so this liability disappears. The claims made on account of sparks from locomotives setting fire to adjacent crops and property often amount to thousands of pounds per annum, for which a railway company is liable to pay compensation.

It is not the actual value of the damage done, though this may be serious enough at times, but in the disability to disprove fraudulent claims.

10. *Rapidity in Steam Raising.*—The time taken with oil fuel is approximately forty minutes.

11. *Shed Economies.*—No cost for firewood. No fires to be raked out. No flues or smoke boxes to clean. No coal to be stacked or weighed. No fire-rakes, shovels, or other equipment necessary with coal.

12. *Practical Experience.*—The following is an abstract from a paper by Mr. B. E. Holloway of the Mexican Railway :

"It does not pay in most cases to keep coal for a lengthened period, but oil fuel can be stocked for a much longer time without detriment, and therefore a six months' stock can easily be held, which in case of failure of supply from one source gives ample time to obtain oil from elsewhere. Coal is just as likely to fail, as was shown during the recent coal strike.

"In the case of the Mexican Railway, the main storage is provided at four points on the system. That at Vera Cruz furnishes the supplies for all other places, and has a capacity of 16,000 tons ; two other points are of 8,000 tons each, and the fourth is somewhat smaller. There are several other places where small storage is erected for the use of branch lines or in cases of emergency. Generally speaking, it will be found that fewer depôts will be needed for oil fuel than for coal, due to the engines being able to carry more oil than coal. Thus, in most cases, an engine will carry enough oil for a round trip, instead of having to load up with coal at the half-journey.

"It is an absolute necessity in order to obtain good results

from the start that the drivers should be properly taught the use of oil fuel. It is no use handing over an engine to a man who has been all his time used to coal and expecting him to get efficiency out of an oil-burning engine. The first requisite in starting oil burning is to obtain one or two practical men thoroughly up in the subject and put them on as teachers. Such men are scarce at present and ask high wages, but they will save their pay many times over.

"Very few of our drivers and firemen had any experience of oil-burning engines, and at first they were rather against the idea. Each engine as it came out of the shops was handed over to its proper crew, who were accompanied by an inspector as teacher. Usually a round trip was sufficient for the learners; after that a travelling inspector occasionally rode the engines for a few miles to give any needed hints, and also to watch the performance of the engines, which often require minor adjustments in order to give the best results. After a few days' trial, the drivers were usually most enthusiastic about the new fuel, but the majority of the firemen did not take at all kindly to it.

"The driver found that he had very little trouble in obtaining a full head of steam, and, in fact, in the earlier stages the chief difficulty was to prevent them wasting steam. The fireman found that though his manual labour was *nil*, the new fuel always required his attention, his hand being constantly on the valves increasing or decreasing the supply of oil or steam. He had been used to putting on a heap of coal and then sitting down while that burnt out. With the introduction of oil fuel a better class of men presented themselves as firemen, and in a few years it is to be hoped that very few drivers will be engaged who have not learnt their work on their own railway.

"At one station the work previously performed by twenty-six men, and requiring frequent use of an engine for shunting in and out coal cars and the movement of ash cars, is now done by two men, who also perform all the work required for the supply of water to a running shed, engines, and a fairly large population of employees and their families."

SECTION II

PRINCIPLES OF COMBUSTION

THE principles involved in the complete combustion of fuel oil are identical with those of coal or any other fuel. In the case of oil, however, the difficulty of arriving at and maintaining complete combustion is much greater, although at first sight it would appear to be a more simple problem. The *primâ facie* evidence of this is in the large number of inventions of oil burners of all types and classes having as their objective the extraction of the greatest amount of heat from the oil.

Briefly stated, it is necessary to break up any fuel into pieces of such size that the oxygen in the atmosphere will unite perfectly with them in combustion. Any deficiency in this respect results in some portion of the fuel passing away as unburnt hydrocarbons and some portion being left behind in the form of ashes or coke. It is also equally important that only the exact amount of oxygen (air) necessary to produce complete combustion should be admitted to the furnace. Any excess of air over and above that actually required produces quite different chemical changes in the gases, having the effect of lowering the temperature in the combustion chamber, and therefore lowering the efficiency. Every invention dealing with the combustion of fuel has as its basis an arrangement whereby the particles of fuel may be brought into perfect contact with the exact amount of air necessary to produce complete combustion. In the case of coal, appliances vary very greatly according to its nature and characteristics, and every fireman knows how difficult it is to burn small slack or bituminous coal on firebars suitable for hard steam coal.

At the same time the analogy between coal and oil burning is very close, and it is necessary to bear this fact

very much in mind when following out the suggestions put forward herein. As a matter of fact these suggestions are intended to appeal to those having intimate knowledge of coal-fired locomotives. One point may illustrate clearly what is meant. Every locomotive engineer knows the serious and immediate effect of incomplete covering of the firebars with live coal. If only a very small portion is exposed for the passage of free air, cooling of the firebox gases occurs and steam pressure drops. Exactly the same thing happens with oil burning when excess of air is admitted, although it seems to have been quite overlooked in many designs of oil-burning fireboxes.

The intention here is to point out the differences in the conditions between the successful combustion of coal and that of oil and to indicate how these conditions can be met. It is therefore a mistake to assume that coal-burning experience is no guide for oil burning. On the contrary, it is an essential guide, but such knowledge must obviously be applied to conditions which are often diametrically opposed to those of the old order.

The nearest approach to the burning of crude petroleum is that of bituminous coal. Both are alike in having a basis of heavy hydrocarbons, requiring for complete combustion a proper admixture of air with the volatile gases, the maintenance of temperature in the combustion chamber, and the proper amount of space.

Of these three essential conditions the difficulties which present themselves are not the same in the two cases. For example, with bituminous coal the main supply of air is taken from below and through the firebars. With an even distribution of coal and a thick and regular fire the air which passes through is broken up and utilised entirely and efficiently in combustion. Assuming a high grade of stoking, it is not possible to pass through an excess of air not used effectively. On the contrary, a portion of the heat thus generated is absorbed in driving off the volatile gases of the coal, and this heat is latent. Latent heat reduces the temperature of the gases above the furnace, and to convert this into complete combustion additional air has to be

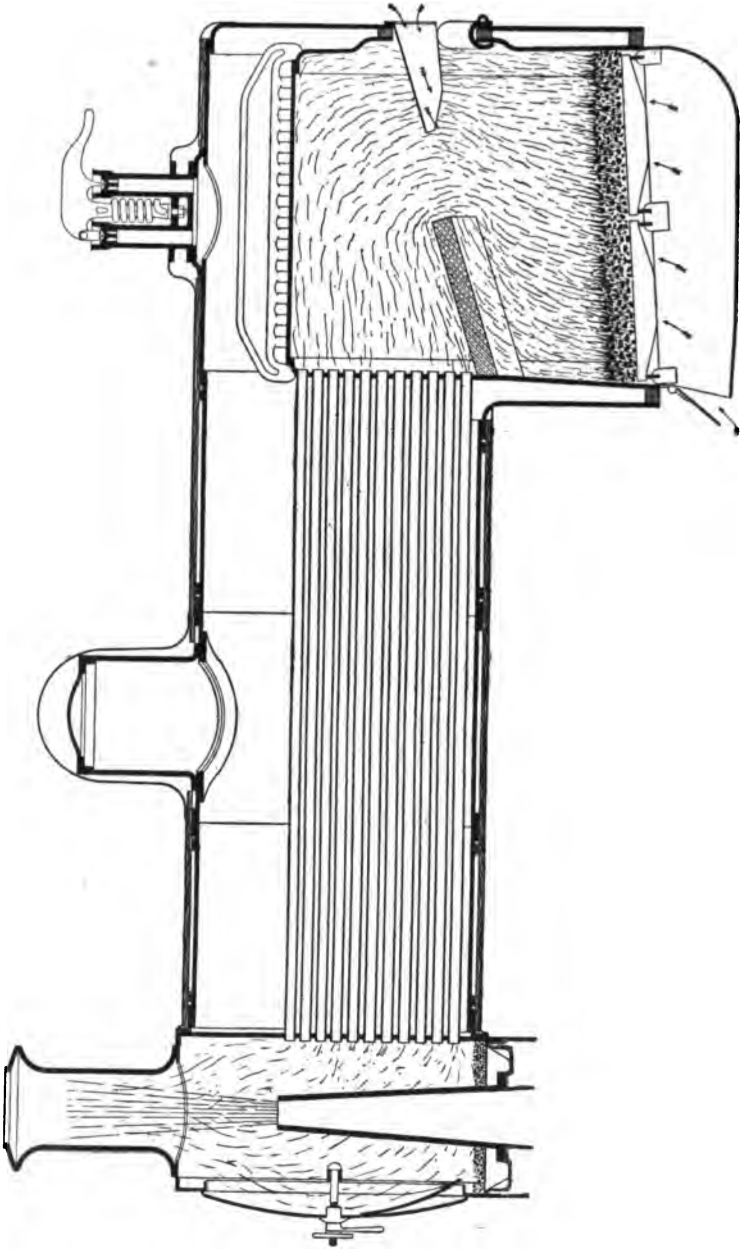


Fig. 1.—Combustion Diagram of Coal-fired Locomotive.

admitted above the coal. It is here where excess air is easily admitted and adjustment is made only with difficulty. In Fig. 1 is shown a section of a locomotive illustrating the manner in which combustion takes place with coal firing, and the admission of the additional air at the firing door.

Something of the same problem arises in the case of oil. As it is not possible to spread oil over firebars or to break it up into lumps, recourse is had to atomisation of the oil by various devices and its distribution evenly over a wide area, so as to represent as nearly as possible the laying of the coal on firebars. The principle of the admission and admixture of the air is, or ought to be, almost identical, that is to say, it ought to follow the direction of combustion wholly and entirely. In other words, the entire quantity of air necessary for combustion should be admitted behind the oil-jet, and the oil spray should so completely cover the area of the firebox that no excess of air should pass through. Unfortunately in practice this is very difficult to attain, as with oil also some latent heat is produced and absolutely perfect combustion is not possible. By perfect combustion is not meant merely the complete burning of the oil, but the complete combustion with the highest percentage of CO_2. (See Table 4, p. 21.)

The percentage of CO_2 may usefully be referred to as the *Excess Air Factor*. The question of smoke prevention is therefore entirely one of air and temperature, but the question of efficient combustion is one of air, temperature, and CO_2.

The quantity of CO_2 being determined by the quantity of air, and this again being determined by the temperature of the furnace gases, it follows that anything disadvantageously affecting the temperature tends to lower the efficiency of combustion and increase the excess air factor. In the case of both oil and coal fuels it has been pointed out that the temperature is lowered by the latent heat of the volatile gases. In addition, no combustion can be perfect where these gases are brought too early into contact with cold tubes, plates, or cold air. It is for this reason that hand-fired furnaces suffer from the opening of the fire

doors and that they benefit by the introduction of previously heated air.

It is therefore most important to avoid condensation of the partly-burnt gases by keeping them from contact with the boiler tubes or plates until combustion has been completed. This is effected generally by building brick combustion chambers, the bricks quickly rising to the temperature of the furnace and acting regeneratively by maintaining the temperature. This method prevents the gases rising vertically and passing away unconsumed among water tubes or through smoke tubes.

The last consideration in this analogy between coal and oil burning is that of space. Obviously the space for combustion should be proportioned in accordance with the quantity of fuel to be burnt and relatively to the quantity of air required. Unfortunately in locomotive boilers this is such a varying factor that each case requires independent treatment, and some compromise has to be effected between maximum and minimum duty. The area of the brickwork and the form which is given to it are both equally important. With oil fuel the burner and brickwork must be considered, one type of burner requiring a different form of brick chamber from that required by another type. In view of the fact that oil spray has much less resistance to the passage of air than coal on firebars, the liability to excess of air on varying loads is much greater in the former case. Given, however, a proper method of air regulation, liquid fuel has a higher percentage efficiency than coal in raising steam because proportionately less latent heat is present and consequently less excess of air is required.

In the practical application of the principles of combustion just described many divergent factors are met with. The effect of these will be considered in the following pages as regards the modifications necessary in fireboxes to burn oil fuel, but it should always be remembered by those accustomed to deal with coal-fired locomotives that while the principles involved are the same the manner is different, the essential difference being in the nature of the fuel to be dealt with. The analogy therefore need not be pursued

further, nor is there any intention in a practical work of this character to consider the chemical or theoretical side of oil fuel. The locomotive engineer wants to know what he must do under the diverse and very trying conditions which confront him to a much greater extent than arises with stationary boilers. For a more analytical study of the subject he is referred to the many scientific text-books, a list of some of these and other publications on oil fuel being given at the end of the book.

Atomisation.—The first essential to the burning of oil efficiently is the complete breaking up of the fuel into minute particles. The word "mist" conveys the idea more accurately. These minute particles, moreover, must be diffused or spread out as much as possible so that the incoming air may completely surround each particle, then the amount of oxygen, which is necessary for combustion, is always present. This is analogous to breaking up coal on the firebars, rendering it full of minute passages, and presenting as great a surface area as possible for combination with the oxygen. The disintegration of coal takes place in a state of incandescence within the furnace, but oil has to be supplied continuously as it is burnt, because with the heat of combustion it becomes immediately vaporised and does not remain incandescent. Regulation of heat, therefore, is dependent upon the quantity of oil supplied to the furnace from moment to moment.

The theoretical quantity of air required to burn 1 pound of oil under conditions of perfect atomisation and admixture is 15 pounds, but considerably more than this quantity is required in practice, usually about 24 pounds, dependent upon the method of atomisation, the arrangements of air admission and regulation, and the operator. The effects of these under the various conditions met with in locomotive practice are dealt with later.

The three methods in use for supplying and pulverising the oil are (*a*) the steam-jet system; (*b*) the compressed-air system; and (*c*) the pressure-jet system. Each method breaks up more or less effectively the crude oil, and in this respect there is little to choose between them. The cost of

doing so, however, is quite different in the three systems, and it is this aspect which has to be carefully considered. Perfect atomisation in itself therefore, although absolutely essential, is not the only condition of successful fuel combustion, nor is it even the most important. The temperature of the oil, the temperature of the furnace, and the temperature of the air have an immediate effect on the degree of combustion of each oil particle. The temperature of the oil passed through the atomiser or burner has an important bearing on the fineness of atomisation. The object of heating is to break down the viscosity (see Table 2) and so render the spray finer. It is necessary to retain this heat in the furnace, and with that object refractory brick linings are employed. The degree to which the oil should be heated depends on its viscosity and flash point. The thicker the residuum, the greater power and higher temperature required to pulverise it. If the temperature of the oil is too high it results in vaporisation, which in some cases may be detrimental, causing chemical breaking up of the oil, known as "cracking." This temperature is usually well above 300° F. and is affected by the degree of compression of the oil. The effect of temperature may be seen comparatively with water, which has a viscosity of 25·5 seconds at 60° F., oil having 1,285 seconds. To bring the viscosity of such oil down to that of water at 60° F. it must be heated to a temperature of about 150° F.

Draught.—The difference of air pressure between the chimney of a locomotive and the air admission opening to the firebox, caused by the velocity of the exhaust steam, creates a partial vacuum in the firebox and provides the draught required for combustion. The draught being thus entirely dependent upon the exhaust steam or upon the blower, it follows that its intensity will correspond therewith. It is in fact a constantly varying factor, the vacuum created ranging from ½ inch to 4 inches of water gauge with coal firing. When the engine is cold, without steam, and therefore without any appreciable natural draught, recourse must be had to a supplementary or artificial draught if complete combustion or quick steam raising are

wanted. This may be effected by compressed air or steam from another engine.

The intensity of draught required for oil burning, or in other words the degree of vacuum in the firebox, is only about one-fourth of that necessary with coal, because the chief resistance to draught in coal firing is the thickness of the bed of coal on the firebars and the small interstices through which air has to pass. With oil fuel, therefore, it would be disastrous to employ the same amount of draught as with coal, because the light particles of atomised oil would be drawn too quickly through the smoke tubes, and away from the side and crown plates, without parting with their heat. The heat of the exhaust gases would be much too high, and with certain forms of burners the flame would be extinguished. In the light of what has already been said regarding the excess air factor, it will be seen that in respect of the usual locomotive draught considerable modification is necessary for oil.

These adjustments can be made in the smokebox by enlarging the exhaust nozzle and by the form and position of the "petticoat," and also by proper damper regulation. The dampers for oil-fuel burning must be made more exactly adjustable than is necessary with coal firing; indeed, this must be obvious, because if the resistance to the passage of air is so much less with oil, the greater quantity will pass through a given opening of the dampers. The forms of dampers and adjustments of exhaust nozzles will be described later, but it may be mentioned here that some form of draught gauge—the simplest form of water-gauge of bent glass tube in the U shape being quite satisfactory—should be provided permanently in the cab and connected by a ½-inch pipe to the smokebox. This will enable the driver to see the variations of draught intensity due to varying degrees of exhaust while running.

Draught for oil fuel therefore resolves itself into a retardation of the gases, sufficient draught only being required to remove the products of combustion as formed. The amount will of course depend on the quantity of oil being consumed at any given moment. Only a slight draught gives a consider-

able velocity, but owing to the higher calorific value of oil the quantity of air necessary for the combustion of 1 pound of oil is 15 pounds as compared with 11 pounds for coal. One pound weight of air occupies 13·14 cubic feet at 60° F.

The following Table 3 gives the velocities of air at 50° F. for pressures in inches of water from 0·1 to 2·0 inches :—

TABLE 3.—AIR VELOCITIES INDICATED BY WATER-GAUGE.

Pressure.	Air Velocity in Feet.	
Inches of Water.	Per Second.	Per Minute.
0·1	20·7	1,248
0·2	29·3	1,758
0·3	35·8	2,150
0·4	41·4	2,485
0·5	46·3	2,778
0·6	50·7	3,043
0·7	54·8	3,287
0·8	58·5	3,513
0·9	62·1	3,726
1·0	65·4	3,927
2·0	92·4	5,547

The foregoing facts and figures are based upon perfect firebox conditions and a temperature of exhaust gases not exceeding 500° F.; the nearer the approach to this condition in practice the nearer perfect the combustion will be.

As the object of draught is to provide the requisite flow of air to the combustion chamber, the area or space necessary for combustion is of great importance. A combustion chamber for coal may be either long and narrow or wide and high. The combustion of the largest proportion of the fuel takes place on the firebars, and it is only the incompletely burned gases that have to be consumed in the combustion chamber. Hence, in order to effect this, additional air has to be admitted above the burning coal by means of

the fire door. In the case of oil, combustion takes place earlier and over a considerably shorter distance, and the area required is larger. Data in connection with the actual space required would serve no useful purpose here, as the types of locomotives differ too considerably. The mere fact that the consumption of coal on locomotive fire grates may be anything between 40 pounds and 100 pounds per square foot of grate area is a sufficient indication. The question, however, will be considered from a practical point of view in Section V., from which it will be easy to draw deductions for any particular case.

Furnace Efficiency.—Combustion may be defined as the union of two dissimilar substances evolving light and heat. In ordinary practice one of these is always the oxygen in the atmosphere, and the other is the fuel employed. Every pound of fuel requires a given quantity of oxygen for its complete combustion, and thus a given quantity of air, which varies with different fuels, but in every case less air prevents complete combustion, and an excess of air causes waste of heat by the amount required to heat the excess of air to the temperature of the escaping gases.

In a summary of experiments made in England, and published in Bourne's large work "Steam, Air and Gas Engines," it is stated that :—

"1. *A moderately thick and hot fire with rapid draught uniformly gave the best results.*

2. *Combustion of black smoke by additional air was a loss.*

3. *In all experiments the highest result was always obtained when all the air was introduced through the fire-bars*" (Babcock and Wilcox).

It is necessary to bear the foregoing remarks well in mind, together with the other data on the principles of combustion given in this section, when considering the deductions arrived at in the sections which follow. First of all the furnace efficiency is affected by an excess of air admission.

The following Table 4 shows the amount of fuel (3) wasted when an excess of air (2), beyond that necessary for complete combustion, is admitted to a furnace, this excess of air being measured by the percentage (1) of CO_2

which the products of combustion in the furnace flues contain.

TABLE 4.—CO_2 ECONOMY TABLE, SHOWING LOSS DUE TO EXCESS AIR.

1. Per cent. CO_2 .	3	4	5	6	7	8	9	10	11	12	13	14	15
2. Excess air	6·3	4·7	3·8	3·2	2·7	2·4	2·1	1·9	1·7	1·6	1·5	1·4	1·3
3. Per cent. fuel loss	60	45	36	30	26	23	20	18	16	15	14	13	12

(1) Percentages of CO_2 by volume; (2) Excess air, so many times the theoretical amount required for combustion; (3) Percentages of fuel lost, cost or tonnage.

The loss of efficiency which ensues from the escape of carbonic oxide unconverted into carbonic acid is due to the much smaller amount of heat given out upon the incomplete combustion of carbon into carbonic oxide. While carbon burned to carbonic acid (CO_2) generates 14,650 B.Th.U. per pound, the same quantity burned to carbonic oxide (CO) gives out only 4,400 B.Th.U. per pound. For every pound of carbon which passes off in the form of carbonic oxide there is therefore a loss of 14,650 – 4,400, or 10,250 B.Th.U., or 69·28 per cent. (Kempe).

A portable and accurate instrument for determining the percentage of CO_2 readily and rapidly is described in Section VIII.

The opposite condition of too little air, or incomplete combustion, is evidenced by the emission of smoke, although it does not by any means follow that no smoke is perfect combustion. Smoke may also be due to an excess of moisture in the combustion chamber, which will lower the temperature of the volatile gases.

The temperature of the combustion chamber is affected by the temperature of the air which enters from outside. Thus if the air is 70° F. the difference between that degree and the temperature of the furnace is absorbed in heating the air and not in evaporating water. It is therefore desirable that the air should be heated prior to admission

to as high a degree as possible by utilising some heat which would otherwise radiate to the atmosphere. Many devices have been patented for the prevention of smoke, but have neglected to take into consideration the effect on temperature, for without the maintenance of high temperature there can be no efficient combustion. The length of flame is determined by the temperature in the combustion chamber, for if the temperature is low the burning hydrocarbons will travel a longer distance before they are consumed.

It will be seen that to ensure the exact quantity of air and maintain the highest temperature the method of air admission is all-important. Even if every other condition were satisfactory, badly-designed air openings and dampers would mean loss of furnace efficiency to a possible extent of 50 per cent.

Oil fuel is composed of 85 per cent. carbon and 12 per cent. hydrogen, approximately. Hydrogen ignites at a temperature below that necessary to ignite carbon, and hence if the temperature of the furnace is low the hydrogen will burn away, leaving the carbon unconsumed, to be carried away in the form of smoke. (See Fig. 21.)

Efficiency of Evaporation.—The efficiency of evaporation is the heat per pound of fuel as fired divided by the calorific value per pound of fuel. Taking the calorific value of oil fuel at 18,500 B.Th.U. per pound, and dividing it by 966·7 B.Th.U.—the heat units required to convert one pound of water to steam at 212° F.—gives 19·13 pounds of water, which should be evaporated at 100 per cent. efficiency. If only 16 pounds of water are evaporated, or 15,467 B.Th.U. per pound as fired, then the ratio of 16 to 19·13 represents the efficiency of evaporation of the boiler and furnace, or 83·6 per cent. This would be a fairly high percentage efficiency, the usual evaporation on locomotives burning coal being nearer 60 per cent. The difference between the figure obtained and 100 per cent. is made up of losses due to incomplete combustion, radiation, etc. The efficiency of evaporation is known as the thermal efficiency.

In order to obtain the actual evaporation at any given steam pressure it is necessary to divide by certain factors

of evaporation corresponding to pressure and temperature of feed water. These factors are calculated on a basis which allows for the boiling point of water being higher than 212° F. when under pressure. Conversely, if the actual quantity of water evaporated is known, it is necessary to multiply it by the corresponding factor to determine the quantity which would have been evaporated from and at 212° F. The list of factors of evaporation is given in Table 5.

The evaporative power of locomotive boilers ranges from 7 pounds to 10 pounds of water per pound of coal consumed, according to the calorific value. The evaporation per pound of oil fuel on a similar basis should be about 15 pounds. The consumption of coal in a locomotive engine at rest is about one-fifth of that consumed when the engine is running. Oil fuel would give a lower percentage.

TABLE 5.—FACTORS OF EVAPORATION.

Temperature of Feed Water in Degrees F.	Boiler Pressure in Pounds per Square Inch.							
	100	120	140	160	180	200	220	240
40	1·219	1·222	1·226	1·229	1·232	1·234	1·237	1·239
50	1·208	1·212	1·215	1·218	1·221	1·224	1·226	1·229
60	1·198	1·202	1·205	1·208	1·211	1·214	1·216	1·218
70	1·187	1·191	1·194	1·197	1·200	1·203	1·206	1·208
80	1·177	1·181	1·184	1·187	1·190	1·193	1·195	1·198
90	1·166	1·170	1·174	1·177	1·180	1·183	1·185	1·187
100	1·156	1·160	1·164	1·167	1·170	1·172	1·175	1·177
110	1·146	1·150	1·153	1·156	1·159	1·162	1·164	1·167
120	1·136	1·140	1·143	1·146	1·149	1·151	1·154	1·156
130	1·125	1·129	1·132	1·136	1·138	1·141	1·144	1·146
140	1·115	1·119	1·122	1·125	1·128	1·131	1·133	1·135
150	1·104	1·108	1·111	1·115	1·118	1·120	1·123	1·125
160	1·094	1·098	1·101	1·104	1·107	1·110	1·112	1·115
170	1·083	1·087	1·091	1·094	1·097	1·099	1·102	1·104
180	1·073	1·077	1·080	1·083	1·086	1·089	1·091	1·094
190	1·063	1·066	1·070	1·073	1·076	1·078	1·081	1·083
200	1·052	1·056	1·059	1·063	1·065	1·068	1·071	1·073
210	1·042	1·046	1·049	1·052	1·055	1·057	1·060	1·062

SECTION III

METHODS OF BURNING OIL FUEL

In the preceding sections emphasis has been laid upon the conditions necessary to ensure the efficient combustion of the oil, and reference was made to the three systems which have been adopted to this end—viz., the Steam-Jet System; the Compressed Air-Jet System; and the Pressure-Jet System. It is proposed to describe these systems in this section, putting forward the points they claim, and examining them from the efficiency point of view.

In order to avoid confusion, comparisons one with another will not be made until the end of the section, but each will be treated on its own merits as to how far it complies with the conditions laid down for ideal operation, bearing in mind that it is a "system" which has to be considered, and not merely a particular form of burner. As a matter of fact, the burner in any system is only the atomiser, and its functions are very circumscribed compared with the equipment as a whole. It is practically limited to two conditions only—viz., (1) the attainment of the highest degree of atomisation, and (2) the form in which the atomised oil is introduced into the furnace.

THE STEAM-JET SYSTEM.

One of the earliest forms of burning petroleum was by means of the steam-jet. Steam was, and still is, employed to break down the viscosity of the oil and to atomise it. It thus serves two purposes, as the viscosity can only be reduced and atomisation rendered possible by raising the oil to the necessary temperature. The simplest form of steam-jet burner is that of a double tube about 18 inches or 2 feet in length in which the tubes are concentric, one

within the other—these tubes to be so arranged that the steam passes at one end into the space between the outer and inner tubes, the oil being supplied to the inner tube at the same end; at the opposite or discharge end the inner tube to be perforated with small holes in a ring around its circumference about 2 inches from the point of discharge, the oil thus mingling with the steam, both being discharged together in the form of a spray. The discharge end of the inner or oil tube would of course be closed, in order to force the oil through the circumferential holes. Such a method is not only very wasteful of steam, but also of oil, as the atomisation could not be carried to the necessary degree of fineness.

Modern steam-jet burners are designed to work more economically, that is, to give the highest degree of atomisation with the minimum quantity of steam.

It is not intended here to describe at any length the many steam-jet systems on the market. There are at least forty of them, but one or two of those which have passed the experimental stage and which embody special features will be referred to. It must not be understood that there are not others equally as good, as the examples are selected as typical only.

The apparatus required with the steam-jet, which is the simplest of all oil burners, consists of the oil tank on the tender, the necessary supply pipes, and the steam connections to the burner. Beyond these and the usual valves, the burner is self-contained and comprises all that is requisite for the regulation of both oil and steam. The oil, which should be heated in the tank, flows by gravity to the burner, although in some systems air compression in the tank is necessary to give the oil a certain "head." This obviously necessitates the use of air-tight tanks and an air compressor.

The admission of air for combustion is arranged and regulated much on the same lines as in coal-fired locomotive fireboxes, but this part of the system is dealt with separately under the head of "Firebox Arrangements."

Full details of any of the following systems can always be obtained from the respective manufacturers.

The Holden Burner.—This system has been designed by Mr. Holden, of the Great Eastern Railway Company, England, after many years of careful study and experience. The object in view has been to combine the systems of coal burning and oil burning in the same firebox with practically no alteration except the covering over of the firebars with firebricks when running solely on oil. The system, there-

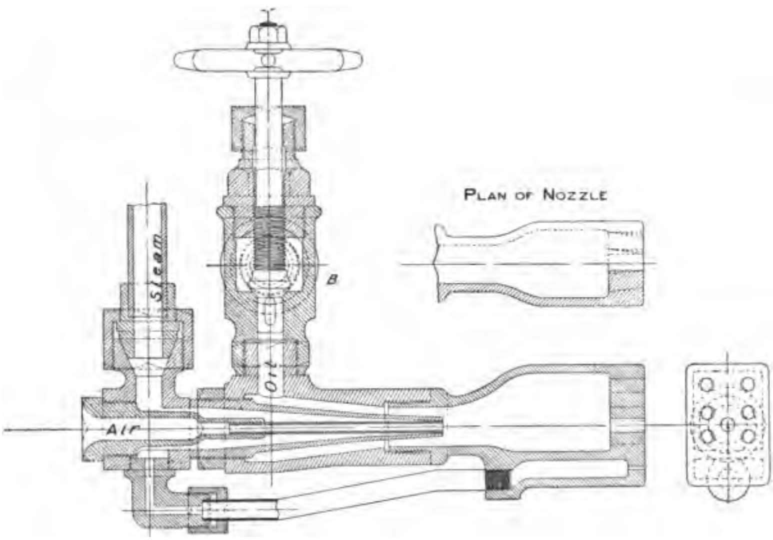


Fig. 2.—Holden's Steam-Jet Burner.

fore, lends itself to either coal firing only, oil firing only, or a combination of coal and oil. There is a good deal to be said in favour of such a system in a country in which coal is the usual fuel, due to its abundance and cheapness, but where the price of oil absolutely puts it out of consideration on a basis of economy. Mr. Holden's object has not been so much to cut down running expenses as to provide against coal strikes. Hence the system is interesting from that point of view, but where these conditions do not obtain a mixed system is at best only a compromise. For a full

description of this system the reader is referred to "Liquid Fuel and its Apparatus," by W. H. Booth, F.G.S., p. 154.

The burner or atomiser is shown in Fig. 2, and is unique of its type. It is made of gun-metal, and its action will be clear from the section. The oil, steam, and air inlets are indicated, air being induced by the velocity of the steam. The special feature is the nozzle through which the mixture of air, steam, and atomised oil passes into the furnace through seven ring holes, inclined to each other at converging angles. The base of the nozzle-box contains a passage for supplementary steam.

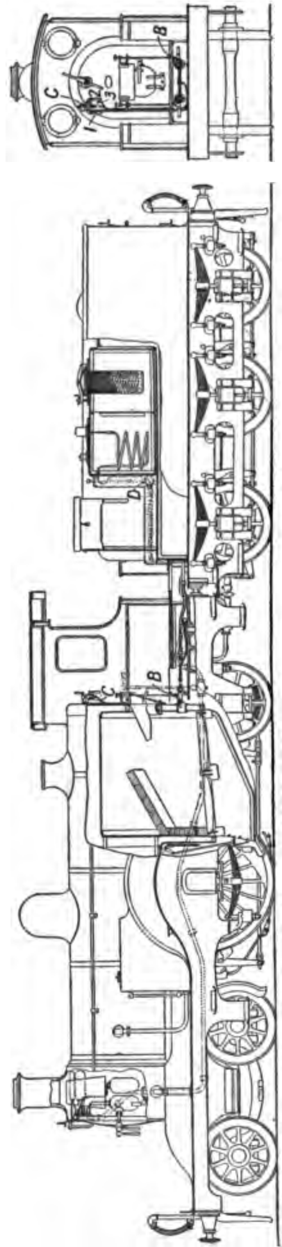


FIG. 3.—Holden's Oil-burning Locomotive.

Fig. 3 shows the application of Holden's system of liquid fuel burning to a locomotive with firebox over 2 feet 6 inches wide. For a smaller firebox a somewhat different arrangement is adopted, one injector only being necessary.

The apertures in the firebox are made by inserting a copper tube, beaded over at the ends, and into this a wrought-iron ferrule is drifted, which makes a perfectly tight joint.

The nozzle of the injector is placed about $\frac{1}{2}$ inch above the centre of the aperture, and the face of the ring $\frac{3}{4}$ inch from front of same.

If liquid fuel is burnt in conjunction with solid fuel a thin layer of slow-burning coal spread over the firebars will be found to be most efficient, with the damper of the ashpan opened sufficiently to give an easy draught and ensure a bright fire.

When liquid fuel is to be used alone, steam is first raised in the boiler by a wood and coal fire kindled in the ordinary manner, and when from 25 to 30 pounds pressure is obtained the fire is levelled over and covered with a layer of broken firebrick of not more than 3-inch cube. This covering is spread so that it is thinnest about the centre of the firebox and well packed round the sides and corners. A few pieces of waste or wood should be thrown in to cause a flame before the liquid fuel is introduced.

Dry steam should be taken from the dome to steam fitting C; the cocks 1 and 2 on the fitting are for admission of steam to cones and rings on injector respectively; the cock 3 is for blowing steam through fuel pipes and injector should they become choked; and the cock D is to admit steam to the heater coil placed in the tank to prevent the fuel solidifying in cold weather.

The fittings necessary for a locomotive, as illustrated, consist of the following:—

Two injector-ejectors.	One four-way piece.
Two regulating valves and gear.	Two tee pieces.
One steam fitting.	Two copper tubes and ferrules.
One stop-cock on tank.	One heater coil connection.

For a locomotive with firebox under 2 feet 6 inches wide the following fittings are required:—

One injector and regulating valve.	One tee piece.
One steam fitting.	One copper tube and ferrule.
One stop-cock in tank.	One heater coil connection.

One of the special claims made for this system is that a bed of incandescent fuel on the firebars helps to maintain the temperature of the firebox when oil supply is shut

off and so prevents undue cooling of the heating surfaces of the boiler.

On the other hand, the combustion area for oil is reduced, and when both coal and oil are in use together there is the inevitable opening of the firing door to supply coal. Hence Mr. Holden has to retain the form of deflecting brickwork over the firing door in order to direct downwards the cold air which enters.

It is claimed that on a month's average with ten locomotives, one using oil and coal and nine using coal only, the consumption of fuel per mile was 23·2 pounds for oil and coal combined and 34 pounds of coal per mile for

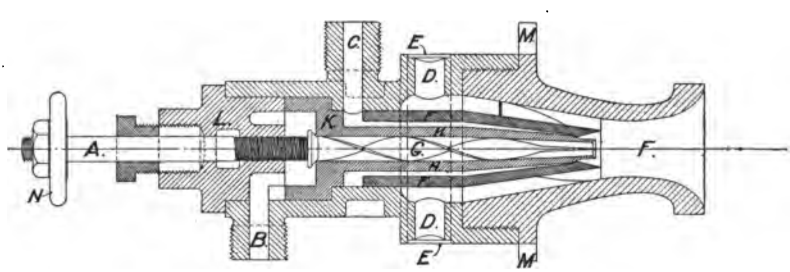


FIG. 4.—Kermode Steam-Jet Burner.

each of the nine locomotives using coal only. The regulation of oil, steam, and air in the burner can be made independently and to a very fine adjustment.

The Kermode Steam Burner.—This burner is shown in section in Fig. 4, and the description of its construction and operation is as follows :—

A. Oil valve spindle for regulating oil supply.
B. Oil admission.
C. Steam admission.
D. Openings for air admission.
E. Moveable perforated strap to regulate air admission.
F. Air cone containing spiral guides.
G. Oil valve.
H. Hollow cone around which steam passes.
K. Base of cone *H*.

L. Gland.
M. Spider for turning round the cone *F*.
N. Valve wheel.

The steam in passing through heats the oil in the inner cone *H*, and both discharge at the needle valve at the back of the air cone *F*. The oil has a swirling motion imparted to it in its passage by the spiral *G*, and oil, steam, and air are jointly discharged into the furnace from the air cone *F*.

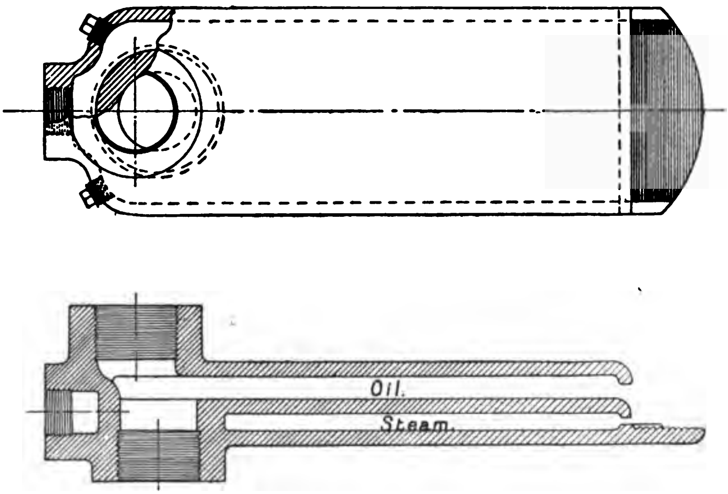


FIG. 5.—Von Boden-Ingles' Steam-Jet Burner.

The flow of air is induced by the steam velocity, and the amount is regulated by the perforated straps *E*. It will thus be seen that the object aimed at is the intimate intermixture of air and oil, the steam performing the duties of heating, atomising and air induction. It is claimed for this system that it has a wide range of capacity, one size of the burner being usually sufficient for ordinary limits of working.

The Von Boden-Ingles' Burner.—The special feature of this burner, which is illustrated in Fig. 5, is the outside atomisation of the oil by the steam impinging on the projecting corrugated lip. This does away with the waste and dripping of oil, and also permits cutting down of the

fire to a candle flame and leaving it in that condition for any length of time.

Another feature is its simplicity of construction, the entire burner being cast in one piece, so that there are no delicate parts to get out of order, and should foreign substances, such as waste, etc., be carried into the burner, they can be readily blown out with steam by using the blow-back valve.

The oil opening is both on the top and the bottom of the burner ; this enables the piping of the oil to either opening, and is an advantage where there is a shortage of room for fitting the oil pipe to the burner.

Best's Burner.—This is an American burner, designed by Mr. W. N. Best, superintendent of the Los Angeles Railway.

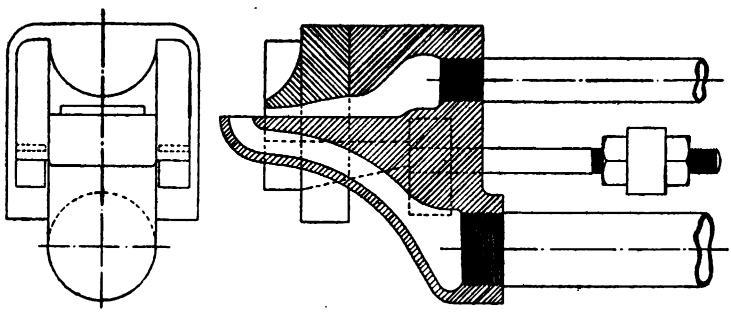


FIG. 6.—Best's Steam-Jet Burner.

It is represented in section in Fig. 6, from which it will be seen that the oil channel is below the steam atomiser. As the oil passes out perpendicularly it is struck by the jet of air or steam issuing horizontally, and is converted into a very fine mist.

The nose or lip of the burner is provided with a hinge, so that it can be quickly removed to clear the steam passage should it become clogged or stopped. An automatic arrangement is also provided for draining the steam passage when the burner is not in operation, and thus water is prevented from being discharged against the brick lining or arch of the furnace.

The opening of the burner can be shaped so as to throw

either a long narrow flame or a fan-shaped blaze 9 feet wide.

These burners are used on the Los Angeles and Tehuantepec Railways and the Mexican Railway.

Advantages of Steam-Jet System.

1. Simple in construction.
2. Involves no pumping or heating apparatus.
3. Low initial cost. Most of the steam-jet systems can be fitted up for a small outlay, from £20 to £50, including all pipes, connections and labour, but exclusive of tanks, firebox, alterations, etc., which are common to each system.
4. Occupies small space.
5. Will deliver up to 500 pounds of oil per burner per hour.
6. Adaptable to any form of flame—that is, flat flame, circular flame, or generally distributed flame.

Disadvantages of Steam-Jet System.

1. The primary disadvantage of the steam-jet system is that it reduces the temperature of the gases in the combustion chamber, which it is vital to maintain at the highest point in order to obtain the highest evaporative results.
2. It is incapable of rapid adjustment, with accuracy, to the varying demands of the locomotive. This is on the assumption that it is considered as an oil burner and not as a combined oil and coal system.
3. It is affected by variations in the steam pressure, and particularly by wet steam. Priming of the boiler has the immediate effect of extinguishing the flame, with some liability to explosion on relighting.
4. If there is any sulphur present in the oil, sulphurous compounds are formed in the combustion chamber, which attack the plates and tubes.
5. It costs as much extra in oil as it draws steam from the boiler, and this varies from 5 per cent. to 12 per cent., plus its lower heating efficiency.
6. When the atomised jet strikes a cold boiler plate,

that is, a plate or surface at a temperature of 500° F. or below, the oil will condense on the surface and not be burnt.

7. Its ultimate economy is dependent on the manipulation by the fireman.

The Texas Oil Company say "that under no circumstances can the admission of steam into the firebox be anything but detrimental to the temperature. If it is reduced to water vapour it gives up its latent heat, only to absorb that heat again upon subsequent evaporation, and will absorb further heat when passing from the furnace as superheated steam. The original heat in the steam was taken from the boiler and should be considered lost as far as any possibility of regaining it is concerned."

As most of the experience with the steam-jet system has been obtained in the United States, where it was universally employed until considerations of efficiency caused careful tests to be made, one or two extracts from the reports of expert investigators will be given.

The report by the United States Navy Board says, in reference to this system : "All steam that enters the furnace will, if combustion is complete, pass up the chimney as steam, also carrying with it a certain quantity of waste heat. The amount of waste heat will depend upon the amount of steam and its temperature at the entrance of the furnace. The quantity of available heat, measured in thermal units, is undoubtedly diminished by the introduction of steam. That when using steam, higher pressures are undoubtedly more advantageous than lower pressures for atomising the oil. That the combustion of liquid fuel cannot be forced to as great an extent with steam as the atomising agent as when compressed air is used for this purpose. This is probably due to the fact that the air used for atomising purposes, after entering the furnace, supplies oxygen for the combustible, while in the case of steam the rarefied vapour simply displaces air that is needed to complete combustion."

Mr. Gaston Launay says "that in oil fired engines using the steam jet the firing must never be forced on any account,

the attending evils being the filling and choking of tubes with soot, burning of the inner shell, of the rivet heads, and causing the boiler to leak. To ensure perfect combustion in locomotives using oil fuel an accurate combination of oil and steam is necessary."

These are the experiences in the United States, but they are confirmed by no less an authority in England than Professor Vivian B. Lewes, who makes the following statement :—

"Some observers have tried to argue that the utilisation of steam for direct pulverisation of the oil adds enormously to the heating effect by producing in this way hydrogen and carbon monoxide, but this, of course, is an utter mistake, as it takes just as much heat to break up the steam as is evolved by the after combustion of the products formed, that is to say, the balance of heat will remain unchanged. The first effect (of steam) is naturally to reduce the temperature of the flames and thereby increase their length, thus moving the point of highest temperature further into the furnace, which has the effect—

"1st, of rendering a large portion of the furnace heating surface entirely useless;

"2nd, of raising the temperature in the combustion chambers to a point which may be hurtful to the material; and

"3rd, of causing the last stage of combustion to take place in the smokebox and chimney."

The remarks made on this system should be read in conjunction with the conditions stated in Section II. Steam for atomisation is equivalent to the presence of water in oil. Mr. C. E. L. Orde, of the firm of Sir W. E. Armstrong, Whitworth & Co., states that it requires seven days to separate the water from oil, the oil during that time being maintained at a temperature of 140° F.

Compressed Air-Jet System.

Many of the steam-jet burners are adapted to substitute compressed air in place of steam. The system was devised

to meet the case of marine boilers, in order to conserve the fresh water which has to be carried, or distilled from sea water. Ten per cent. loss of fresh water would make the steam-jet system prohibitive in most cases, and of course this would also mean 10 per cent. less boiler capacity, or the installation of a supplementary boiler to provide only the steam for the atomiser.

The compressed air-jet system obviously requires an air compressor. In early designs air was used at pressures as high as 80 pounds to the square inch, but latterly claims of efficiency have been made for atomisers using air at a few pounds pressure only. After the compressed air has passed the nozzle of the burner it immediately expands, and in so doing gives up the heat absorbed during compression. Hence a considerable cooling effect occurs in the combustion chamber, which also tends to lower the general temperature. The compression and subsequent expansion of air and other gases is the fundamental principle of refrigerating machines, and it does not seem scientific to introduce a refrigerating effect into a combustion chamber.

In order to compress air power has to be expended, and this power at various air pressures is approximately 1 horse-power for 14·7 pounds pressure (2 absolute atmospheres), 2 horse-power for 44·1 pounds pressure, and 2·75 horse-power for 73·5 pounds pressure—at the rate of 1 pound of air per minute, or 60 pounds of air per hour. As each pound of oil fuel requires about 25 pounds of air for complete combustion (in practice) for every 100 pounds of oil fuel per hour, 2,500 pounds of air are required. Of this total at the lowest pressure, 40 horse-power per hour would be required if all the air for combustion were so supplied. About one-tenth, or 4 horse-power, is required by the atomiser, the remaining nine-tenths being admitted in the usual way. One hundred pounds of oil fuel will evaporate 1,500 pounds of water, and assuming a high engine efficiency of 15 pounds per indicated horse-power per hour, this would represent 100 horse-power, or 1 horse-power per pound of fuel. Hence, under the very best conditions, 4 per cent. of the boiler evaporation would be required for atomising

purposes, not allowing for loss in transmission of air in pipes and the cooling effect of expanded air in the furnace. It has been proposed to heat the compressed air in order to minimise the cooling effect of expansion, but this again means more power. In some cases air compressors take more steam to drive them than would be required for atomisation direct.

The air jet is an ideal system for producing intense localised heat, such as is necessary in metallurgical processes, or where a blast effect is required. This is the very opposite of those conditions so imperative in the furnaces of oil-fired boilers.

For the foregoing reasons and others which are obvious the compressed air-jet system is not suitable or adapted for locomotive oil burning.

The Pressure-Jet System.

This system, as its name implies, depends upon the supply of oil under pressure for atomisation. Heavy oils, such as the fuel oils being dealt with in this book, cannot be atomised at ordinary atmospheric temperatures, as their viscosities do not allow even of ready flow. It is therefore necessary to heat the oil to a temperature at which the viscosity entirely breaks down and this varies between 200° F. and 300° F. Heaters therefore have to be employed. The atomisers usually employed in this system have one common feature, namely, the extreme fineness of the discharge hole in the nozzle, the holes varying by decimals of a millimetre, from 1 millimetre to 3 millimetres in diameter, according to the amount of oil required. Hence it is necessary to use filters or strainers through which the oil must be passed before reaching the burner. These filters are provided with gauze wire or perforated metal plate, the mesh or holes in the final process of filtration being about 1 square millimetre in area. In order to raise the oil to the required pressure, which also varies in different systems from 30 pounds to 150 pounds per square inch, a steam pump has to be provided.

The arrangement of the system is illustrated diagrammatically in Fig. 7.

The oil passes from the supply tank first to a filter, which removes any grit or foreign matter larger than a 2 sq. mm. hole; it then flows to the steam pump, which raises it to the required pressure; from the pump it passes through the heater, absorbing heat from high pressure steam, and from thence in its heated state through a second and final filter with 1 sq. mm. holes or mesh to the burner or burners.

The following is a description of the several parts just enumerated.

Filters.—The first filter is usually designated the suction filter and the second the discharge filter. The design is practically the same for both; the suction filter is not subject to any greater pressure than the weight of the oil behind it, but the discharge filter has to pass the oil at the working pressure, and this may reach 200 pounds per square inch. Filters are designed with duplicate filtering chambers and bye-passes, so that one half can be in use while the other is being cleaned or held ready for service.

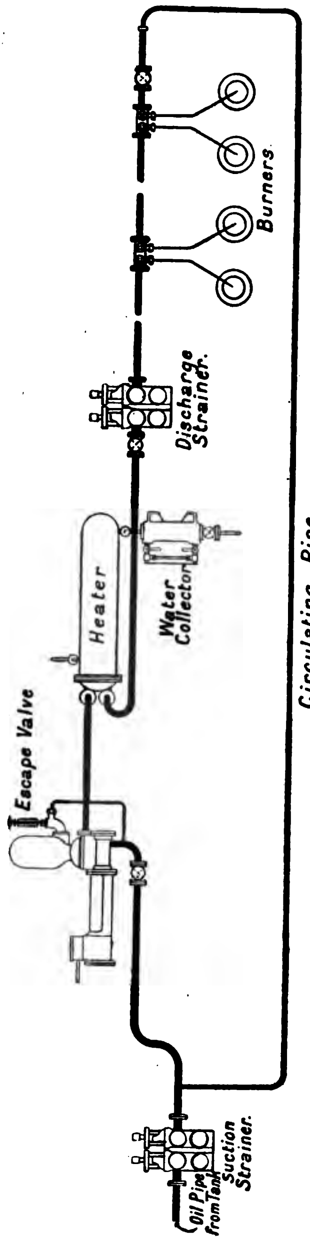


FIG. 7.—Diagram of Pressure-Jet System.

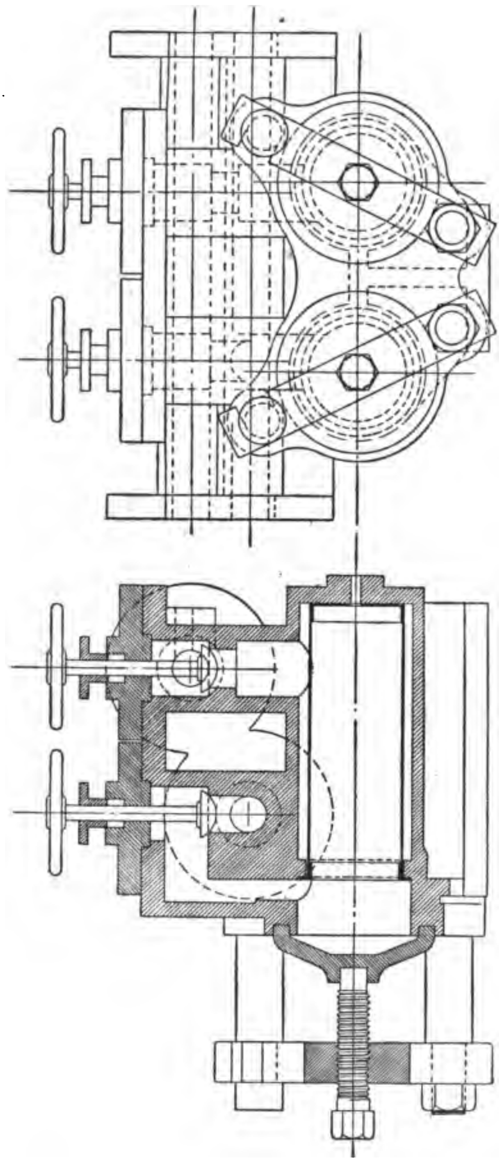


FIG. 8.—Wallsend-Howden Oil-Fuel Filter.

Fig. 8 represents the type supplied by the Wallsend Slipway and Engineering Co., Ltd., and Fig. 8A shows the design of the Meyer-Smith filter.

In locomotive applications it is usual to construct the first filtering medium within the oil tank, placing it over the discharge opening, in order to conserve the space which a suction filter would occupy outside the tank. This inside filter is simply a large inverted cap or cover made of steel plate perforated with 2 millimetre holes, the holes having a

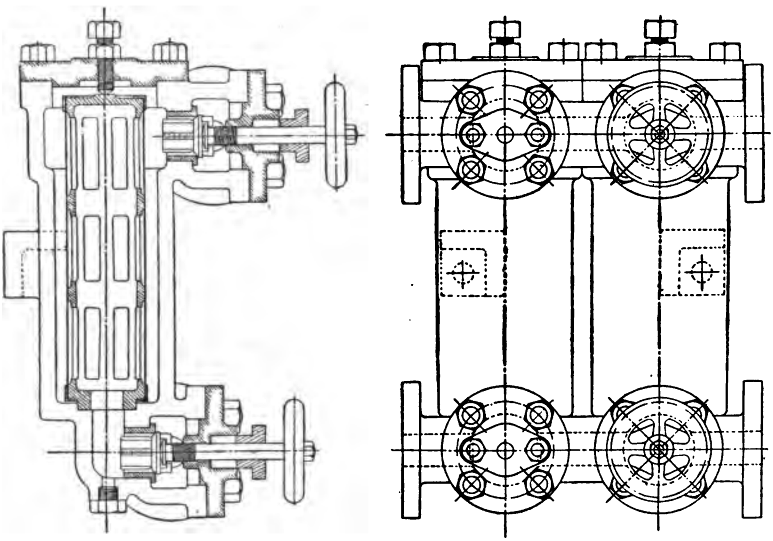


FIG. 8A.—Meyer-Smith Oil-Fuel Filter (Duplex Delivery Filter).

total area of not less than 15 square inches. The cover is placed over the discharge pipe, which stands up about 4 inches inside the tank, and hence the cover should be about a foot in diameter and stand a foot in height. Other methods are adopted where the cover arrangement is not convenient, but in any case it must be easily removed for cleaning purposes.

The second or discharge filter should be provided with caps on the chambers held down by a link bar and set screw, or by hinged bolts, in order to remove and replace the filter bags in a short time.

Pumps.—The pumps found most suitable for liquid fuel work are those of the direct double-acting type, in universal use for boiler feeding purposes. They are made specially for oil fuel by the Worthington Pump Company, Tangye, Weir, and many others. Owing to the viscosity of the oil and the necessity of maintaining a constant and steady pressure, air vessels must be fitted either to the oil chamber or between the pump and the heater. These air vessels should have a capacity of five times the capacity of the oil cylinders.

With regard to the oil capacity per hour, not more than one-fifth of the rated capacity as a boiler feed pump should be taken—in other words, the number of strokes per minute for oil should be one-fifth of those for maximum duty for water. Thus a boiler feed pump having eighty strokes per minute could be used satisfactorily as an oil pump at sixteen strokes per minute, with a correspondingly reduced capacity. Any higher stroke speed will not result in more oil being pumped, as the oil will not flow past the valves above a certain rate. It is in fact necessary that the oil should be at a temperature of not less than 80° to 120° F. to flow evenly.

Table 6 gives, in the second column, the discharge capacity, in pounds of oil per hour, of the Worthington duplex horizontal type, and in the third column the normal rating as a boiler feed pump.

Table 7 contains the factors of multiplication to ascertain the discharge capacity of any reciprocating pump, and the results obtained must be divided by 5 when the pump is to be used for pumping heavy oil at temperatures between 60° and 100° F.

An important detail is the ratio between the steam and oil cylinders. The ratios given in Table 6 are quite satisfactory for steam pressures of 140 pounds and upwards, where the oil pressure does not exceed 150 pounds per square inch. In some cases, however, it is desirable that the pump should operate with steam at 70 or 80 pounds pressure, and in that case the oil cylinder must be made correspondingly smaller in diameter. This is usually done by fitting

a liner into the cylinder, but the efficiency of the pump is thereby lowered.

Table 6.—Capacities of Worthington Pumps (Duplex Horizontal Type) in Pounds of Water per Hour and at Twenty Strokes per Minute.

Size of Pumps (in inches).	Capacity at 20 Strokes per Minute (lbs. per Hour).	Normal Rating for Boiler Feed Water (lbs. per Hour).	Max. Speed for Water (Strokes per Min.).
$3 \times 1\frac{3}{4} \times 2\frac{1}{2}$	465	2,068	80
$3 \times 2 \times 3$	729	3,240	80
$3\frac{1}{2} \times 2\frac{1}{4} \times 4$	1,232	5,133	75
$4\frac{1}{2} \times 2\frac{3}{4} \times 4$	1,841	7,672	75
$5\frac{1}{4} \times 3\frac{1}{2} \times 5$	3,736	15,566	70
$6 \times 4 \times 6$	5,841	21,095	65
$7\frac{1}{2} \times 5 \times 6$	9,129	32,968	65

Specific gravity of oil taken at 0·9.

The figures in the third column, divided by 10, give the number of gallons of water per hour.

For oil duty these pumps should be fitted with an automatic release valve with an adjustment for operation at varying pressures such as 100, 125, 150, 175, and 200 pounds. Any excess of pressure would thus cause oil to flow back to the suction side of the pump. The arrangement has this advantage, that such escape or overflow is indicated at once by the irregularity of the strokes of the pump, apparent to both eye and ear.

These force pumps are not adapted for suction. They should therefore be so placed that the oil from the tanks flows to them by gravity.

Heaters.—In this system the oil is heated under pressure by steam from the boiler, the oil passing slowly through a vessel in which steam coils are placed or in which the steam surrounds tubes through which the oil passes. The principle is the same in both cases, the objects being the extraction by the oil of the greatest amount of heat from a given

TABLE 7.—DISCHARGE FROM RECIPROCATING PUMPS.

Table of Constants which, multiplied by effective number of strokes per minute, give the discharge in gallons per hour.

Stroke of Pump (in Inches).	Diameter of Pump (in Inches).												
	2.	2½.	3.	3½.	4.	4½.	5.	5½.	6.	7.	8.	9.	10.
1	0·679	1·061	1·528										
1½	1·019	1·592	2·292	3·120									
2	1·359	2·123	3·057	4·160									
2½	1·698	2·654	3·821	5·200	6·795								
3	2·038	3·185	4·586	6·240	8·154	10·31							
3½	2·378	3·715	5·350	7·280	9·513	12·03	14·86	17·98					
4	2·718	4·247	6·115	8·320	10·87	13·74	16·98	20·84	24·45				
4½	3·057	4·777	6·879	9·360	12·23	15·45	19·11	23·16	27·50				
5	3·397	5·308	7·644	10·40	14·95	17·19	21·23	25·68	30·06	41·60			
5½	3·737	5·839	8·408	11·44	15·59	18·91	23·35	28·25	33·63	45·76			
6	4·077	6·370	9·173	12·48	16·31	20·63	25·48	30·81	36·68	49·92	65·20	82·52	
6½	4·416	6·901	9·937	13·52	17·67	22·35	27·60	33·39	39·73	54·08	70·63	89·40	
7	4·756	7·432	10·70	14·56	19·02	24·07	29·73	35·95	42·79	58·24	76·06	96·27	
7½	5·096	7·962	11·46	15·60	20·38	25·79	31·85	38·52	45·84	62·40	81·49	103·1	
8	5·426	8·494	12·23	16·64	21·74	27·50	33·97	41·09	48·91	66·56	86·93	110·0	135·8
8½	5·778	9·024	12·99	17·68	23·10	29·22	36·10	43·65	51·95	70·72	92·36	116·9	144·3
9	6·115	9·555	13·76	18·72	24·46	30·94	38·22	46·23	55·00	74·88	98·10	123·7	152·9
9½	6·455	10·08	14·52	19·76	25·82	32·66	40·34	48·79	58·50	79·04	103·5	130·6	161·3
10	6·795	10·61	15·28	20·80	27·18	34·38	42·47	51·35	61·12	83·20	108·7	137·5	169·8

quantity of steam and considerations of design for accessibility and cleaning. The steam in the heater has to be maintained at the boiler pressure in order to raise the oil to the temperature required, which ranges between 200°

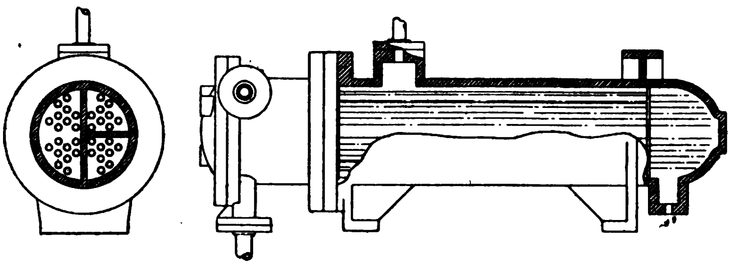


FIG. 9.—Wallsend-Howden Oil-Fuel Heater.

and 300° F. Table 8 gives the temperature of saturated steam at different pressures. From this table it will be seen that steam at 150 pounds pressure has a temperature of 358·2° F., and in giving up its heat to the oil it changes from the condition of steam to that of water. Hence the effect of latent heat losses has to be allowed for, in addition to radiation losses in the steam pipe and the exterior surfaces

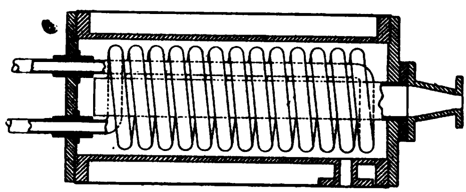


FIG. 10.—Meyer-Smith Oil-Fuel Heater.

of the heater. Heat units are also lost in the oil as latent heat losses occur in changing its condition from a liquid to a vapour, at the higher temperature. Hence steam at 150 pounds and at a temperature of 358·2° F. can never give up the whole of its heat units to the oil, the efficiency depending on the type of heater and the rate of flow of the oil. Usually heaters are designed to heat the oil to 280° F.,

as any higher temperature would involve sizes altogether impracticable.

Three different types of heaters are shown in Figs. 9, 10 and 11.

Fig. 9 is the type adopted by the Wallsend Slipway and Engineering Co., Ltd. It consists of oil admission and discharge chambers and a number of steel tubes through which the oil circulates. Steam is admitted to the body of the heater and surrounds the oil tubes, the condensed steam passing into a collector—shown in diagram in Fig. 7—from which the amount of condensed water can be seen and drained off.

Fig. 10 is the Meyer-Smith type, in which the oil occupies the body of the heater and the steam is passed through a

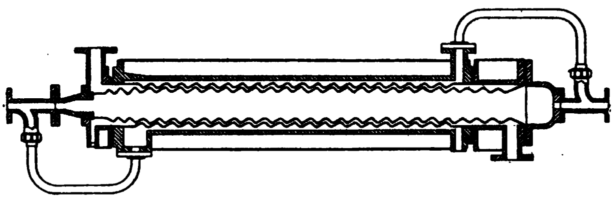


FIG. 11.—American Type Oil-Fuel Heater.

coiled pipe. As oil does not give up its heat so readily as steam, the radiation losses from the body of this heater, assuming it to be well lagged with good non-conducting material, should be small.

Fig. 11 is an American type of heater adopted officially by the United States Navy Board. The oil passes through a very narrow passage formed by the convolutions of two concentric tubes pressed into the form of a spiral thread. The steam occupies the space inside the inner tube and outside the outer. The surface of the oil thus exposed to the heat of the steam is very great in comparison with its bulk, and reaches a high temperature very quickly. An excellent feature of this heater is the facility with which it can be taken apart and replaced by the "unscrewing" of the inner tube from the outer and exposing all parts and surfaces for inspection and cleaning.

Heaters of any type should not be made of cast iron. Cast steel, or rolled or solid drawn steel is the only reliable metal. All steam and hot oil pipes should be well lagged. A 4-inch diameter pipe, 50 feet long, conducting steam at 100 pounds pressure will radiate heat equivalent to 40 pounds of steam per hour, an appreciable percentage of a boiler capacity. No such pipes should therefore be exposed on a locomotive, nor any surfaces from which radiation takes place.

TABLE 8.—TEMPERATURE OF SATURATED STEAM AT DIFFERENT PRESSURES.

Pressure in lbs. per square in. above Vacuum.	Temperature in Degrees Fahrenheit.	Pressure in lbs. per square in. above Vacuum.	Temperature in Degrees Fahrenheit.
10	193·25	105	331·13
20	227·95	110	334·56
25	240·04	115	337·86
30	250·27	120	341·05
35	259·19	125	344·13
40	267·13	130	347·12
45	274·29	140	352·85
50	280·85	150	358·26
55	286·89	160	363·40
60	292·51	170	368·29
65	297·77	180	372·97
70	302·71	190	377·44
75	307·38	200	381·73
80	311·80	225	391·79
85	316·02	250	400·99
90	320·04	275	409·50
95	323·89	300	417·42
100	327·58	350	424·82

Auxiliary Apparatus.—The auxiliary fittings of this system consist of pressure gauges for oil and steam, thermometers, non-return valves, distributing valve boxes, steam pipes, oil pipes, return oil circulating pipes, and burners. Their position is shown diagrammatically in Fig. 14, illustrating

the Wallsend-Howden system. They are referred to again in Sections V. and VI.

Advantages of the Pressure-Jet System.

1. Oil is atomised at a temperature approximating to its boiling point, in which state atomisation is the easiest and most perfect.
2. The spray is evenly distributed and the flame is short, thereby ensuring complete combustion at a short distance from the nozzle.
3. The quantity of air can be more nearly regulated to correspond with theoretical requirements than in other systems.
4. Hot oil and hot air are introduced at a nominal consumption of power. The steam required for the pump and for heating being about 1 per cent. of the boiler capacity.
5. Evaporative efficiency of 80 to 83 per cent. on stationary boilers.
6. Does not produce any deleterious products of combustion.
7. High furnace temperature maintained.
8. High percentage of CO_2.
9. Low temperature of exhaust gases.
10. Perfectly silent operation.
11. Smokeless combustion.

Disadvantages of the Pressure-Jet System.

1. Necessitates the apparatus described.
2. Dependence on pump for compression of the oil. This is the only moving part, and, owing to the excellence of workmanship and reliability of the type of pump described, this does not form a serious objection.
3. Entails considerable capital outlay, which ranges from £100 to £400, according to the capacity of the locomotive. The economy of the system and the increased evaporation possible gives an additional efficiency of 10 per cent. over the steam-jet system, all conditions being equal. It will therefore soon repay the extra capital outlay involved by economy in oil.

The United States Navy Board, in its report on oil-burning apparatus, says "that the efficiency of oil-fuel plants will be greatly dependent upon the general character of the installation of auxiliaries and fittings, and therefore the work should only be entrusted to those who have given careful study to the matter, and who have had extended experience in burning the crude product. The form of the burner will play a very small part in increasing the use of crude petroleum. The method and character of the installation will count for much; but where burners are simple in design and are constructed in accordance with scientific principles, there will be very little difference in this efficiency. Consumers should principally see that they do not purchase appliances that have been untried, and have been designed by persons who have had but limited experience in operating oil devices."

Descriptions of particular types of pressure-jet systems will be found in the section which follows.

SECTION IV

PRESSURE-JET SYSTEMS

THE WALLSEND-HOWDEN PRESSURE SYSTEM (PATENT).

THIS apparatus is manufactured by the Wallsend Slipway

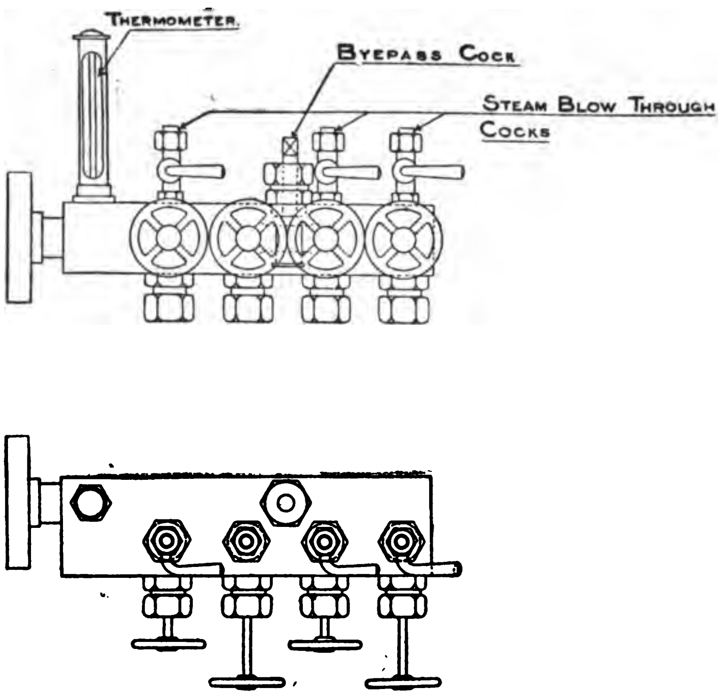


FIG. 12.—Wallsend-Howden Distribution Valve Box.

and Engineering Company, Ltd., of Wallsend-on-Tyne, England.

The oil is delivered to the burners under high pressure by

means of special pumps and at a temperature of 250° F. to 300° F. Atomisation of the oil is therefore obtained without the use of steam as the atomising agent. In order to reach the burners the oil passes through a specially designed distribution valve box, fitted with steam cocks to each burner valve, so that when any oil supply valve is closed

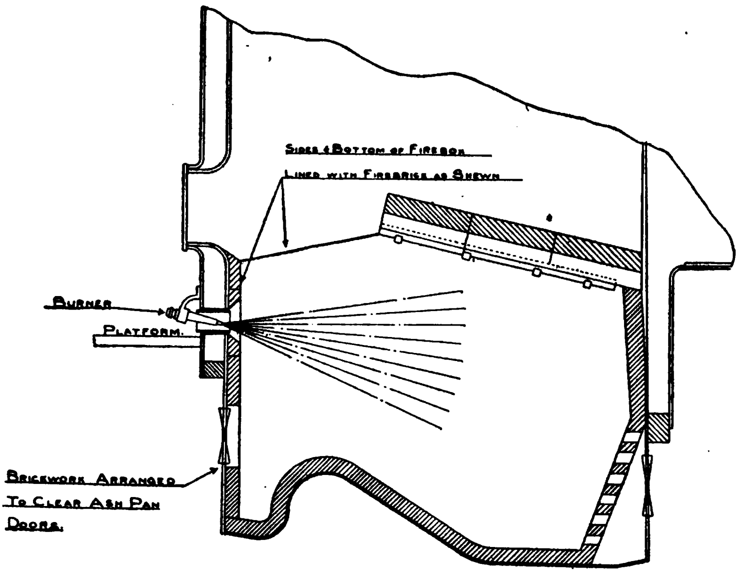


Fig. 13.—Wallsend-Howden Firebox Arrangement.

the steam cock can be opened to steam supply and steam blown through the pipe to the burner, so clearing the pipe and burner of oil, which would otherwise carbonise owing to the heat of the furnace.

Figs. 13 and 13A show the Wallsend-Howden system fitted to a small locomotive firebox, which illustrate an alternative method of burners and air admission at each end of the ashpan.

Fig. 14 is a diagrammatic arrangement of the several parts of the apparatus, as designed for a locomotive with a large firebox.

This system is also provided with a special device for raising steam without recourse to wood or other fuel and without the necessity of taking steam from any exterior source. The advantage of this will be obvious for many railways, especially those with long single tracks where wood and coal are unobtainable, and where it is impossible to start up by auxiliary steam.

No change of burner is necessary. This supplementary apparatus consists essentially of a hand pump and auxiliary

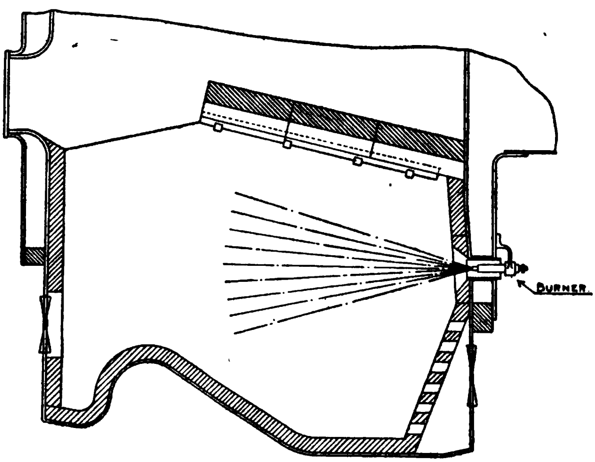


FIG. 13A.—Wallsend-Howden Firebox Arrangement.

heater in the form of a double concentric tube through which the oil passes.

The arrangement is shown in Fig. 15.

The double concentric tube for heating the oil is introduced into the firebox at a point a few inches below the burner, so that the extreme end is within the flame from the burner. The cold oil enters the inner tube and is discharged at the other end, passing thence along the space between the inner and outer tubes to the burner. The initial heat is provided by a handful of oily waste ignited under the far end of the heating tube, and after a few strokes of the hand

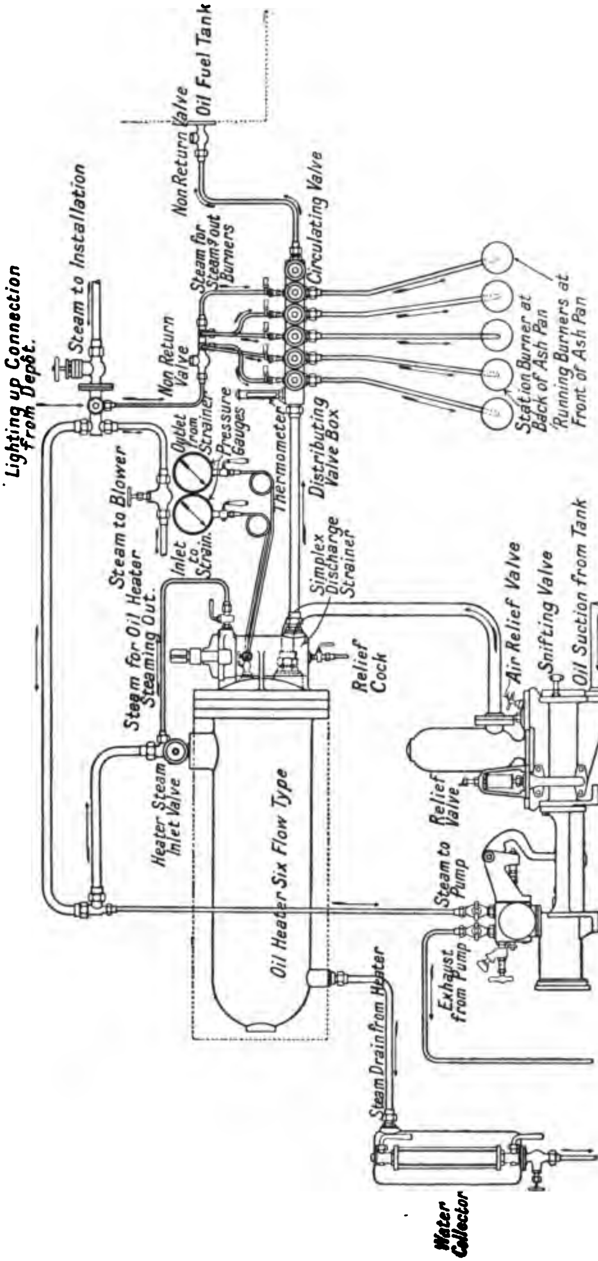


FIG. 14.—Diagrammatic Arrangement of Pipes and Fittings for Pressure-Jet System.

pump the oil will light at the burner and continue to heat the fuel automatically. The wörking of the hand pump involves no appreciable amount of manual labour, as only

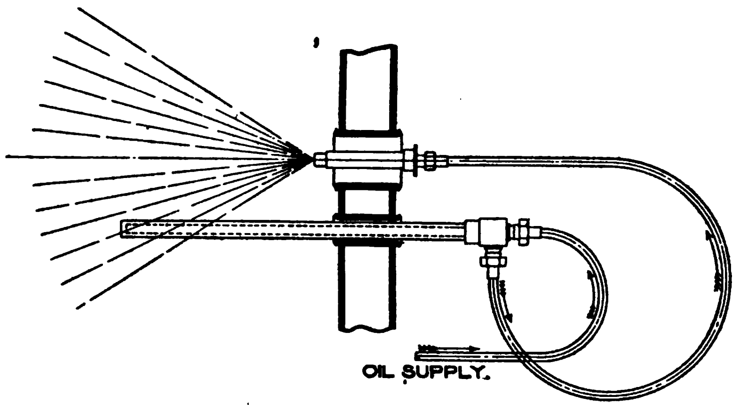


FIG. 15.—Device for Steam-raising with Fuel Oil.

a few strokes every few minutes are necessary to maintain the pressure of the oil. The degree of heat is regulated by inserting the concentric tube at any desired distance within the flame area.

The oil is forced into the furnace in the shape of a conical

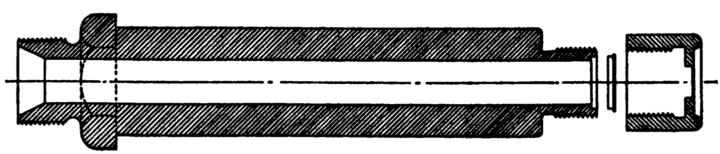


FIG. 16.—Wallsend-Howden Burner.

spray of exceedingly fine particles, which burst into flame at a distance of 6 to 8 inches from the nozzle. The flame being conical, and there being no firebars fitted in the furnace, the whole area of the furnace is available for heating surface. As there is no firing door to be opened, there is none of

that straining action which results from unequal expansion and contraction, due to rapid changes consequent on the opening of the door in coal stoking.

The Wallsend-Howden burner is illustrated in Fig. 16. It consists of a plain tube, one end of which is arranged for the connection of the oil supply pipe and to the other is attached the nozzle or atomiser. Between the burner tube or body and the nozzle is placed a diaphragm, consisting of a small metal disc, which is perforated by one, two, or three holes drilled at an angle. These holes are graduated with great exactness to millimetre gauges, and thus form a series of standard sizes or numbers by means of which any desired capacity of oil per hour can previously be determined. A list of these capacities at varying oil pressures is given in Table 9. In its passage through the holes in the diaphragms the oil is given a rotary movement, which it retains in passing through the central discharge hole of the nozzle.

From the foregoing it will be seen that with the Wallsend-Howden system it is not possible to regulate the admission of oil to the burners by means of the oil valves, the regulation being effected by the oil pressure or by cutting in and out one or more burners. This arrangement greatly simplifies the question of air admission, as the quantity of oil which will be supplied by any given burner is always predetermined.

Steam being raised or available, the oil is admitted to the system, and at the same time steam is turned on to the heater. Before opening up any of the burners the pump must be started and the oil circulating valve opened, thereby circulating the oil through the heater and back to the suction side of the pump or to the tank. In the course of only a few minutes the oil will have attained a temperature of 200° F., at which the burners may be lighted.

Before admitting oil to the furnace a piece of cotton waste, soaked in kerosene, should be ignited and thrown within the firebox.

The normal working pressure of the oil should be about 150 pounds per square inch for ordinary steaming, but must be regulated to suit the amount of steam required.

TABLE 9.

Table showing Approximate Quantities of Oil that can be passed through each Burner per Hour with the following Combination of Nozzles and Diaphragms. These Quantities will be passed when using Mexican Oil at a Temperature of 260° F.

Specific gravity of oil (at 60° F.) = 0·947.
Viscosity of oil at 100° F. = 1,650.
" " at 200° F. = 136.
" " at 250° F. = 74.

Pressure per sq. in.	Nozzle No.	Diaphragm No.	Quantity of Oil passed per Hour.
lbs.			lbs.
125	10	210	135
"	12	212	160
"	13	213	180
"	16	216	240
"	18	218	270
"	20	220	300
"	22	222	360
"	24	224	425
"	26	226	525
150	10	210	140
"	12	212	170
"	13	213	190
"	16	216	255
"	18	218	290
"	20	220	325
"	22	222	395
"	24	224	465
"	26	226	575
175	10	210	145
"	12	212	180
"	13	213	200
"	16	216	275
"	18	218	310
"	20	220	350
"	22	222	420
"	24	224	500
"	26	226	620

The condition aimed at is a bright, clear flame fully filling the firebrick chamber. There should be a slight trace of smoke at the chimney, and this will indicate that there is no excess of air being supplied for combustion.

The temperature of the oil should be raised to suit the pressure at which it is being sprayed and the class of oil which is being burned, so as to give the maximum efficiency, and this temperature will be about 150° to 300° F. The most suitable temperature will be found by trial and experience with the different classes of oil.

Mexican and other heavy oils require to be burned at the higher temperatures.

Experience shows that the greater the viscosity of the oil, the higher the temperature required for efficient combustion.

Care should be taken that the stand-by strainers are kept clean, so that in the event of the working strainer becoming choked they can be quickly changed over.

Pressure gauges are provided on the inlet and outlet sides of the strainers, and the difference between the pressure shown on these gauges will give an indication of the condition of the working strainers.

An air valve is fitted to the air vessel, and should be opened at the same time as the suction valve on the tank; the pump is then started and the air vessel well charged with air so as to ensure a steady pressure of oil to the burners: when the air vessel is fully charged the air valve can be shut down.

The design and construction of this apparatus is excellent in every way. Steel is used throughout for all parts subject to internal pressure, and the burner bodies are made from solid forgings.

This system has been applied to locomotives in many parts of the world, particularly on the nitrate railways (Chili), and on several other railway systems in South America.

The Meyer-Smith Pressure System.

This apparatus is manufactured by Smith's Dock Company, Ltd., North Shields. In all essential details of arrange-

ment it follows the description given of a pressure system in Section III. In details of manufacture it has special features, for which specific claims are made. The heater

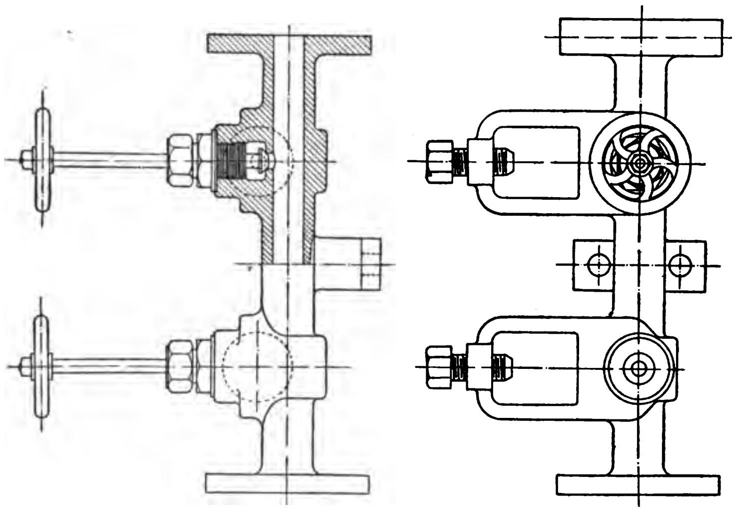


FIG. 17.—Meyer-Smith Burner Distributing Chest.

which is shown in section in Fig. 10 is made of wrought steel, with all branches and flanges electrically welded on, which ensures a perfectly oil-tight vessel. Both end covers are made from steel plates. The steam is passed through

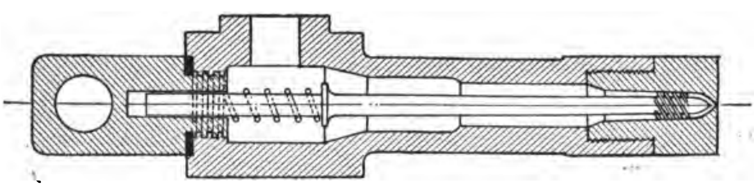


FIG. 18.—Meyer-Smith Burner.

the coil and the oil is contained in the heater itself, and this is found to give the best results.

The patent burner holder and distributor is shown in Fig. 17, from which it will be seen that the control valve for each burner is situated in the chest opposite to its respective

burner, but this design is essentially for land installations, as it would have to be modified for locomotive requirements.

The Meyer type liquid fuel burner is shown in section in Fig. 18.

This system is a low-pressure system, the oil being supplied to the furnace at 30 to 70 pounds per square inch pressure.

Other Pressure-Jet Systems.

As already stated in the previous section, there are several makers of oil-burning apparatus which embodies all the details already described, and for which each maker has his own particular claims. There is nothing distinctive in any of them to call for special notice, and they have not yet been adapted to locomotive requirements except in an experimental way. Most of these systems depend on some form of air admission which is suitable only for stationary boilers, and average evaporation required can be determined and depended upon very accurately. For instance, with a given furnace arrangement, size of chimney, temperature of feed water, hot-air admission, and facilities for regulating the air and oil supply to a nicety, the percentage CO_2 in the flues and the temperature of the flue gases can be maintained with practically no variation. It is a very different case with locomotive duties, where the conditions are so variable and the range so wide that it is a highly technical problem to get the best average results.

It does not follow, therefore, that because a system of burning liquid fuel has been quite successful on stationary boilers it will be equally satisfactory on locomotives. So far as the performance of the purely mechanical equipment is concerned, certain guarantees can be given, but the boiler efficiency is dependent on several factors entirely, or very largely, independent of the method of supply of oil. These factors, which have never yet been fully appreciated because with the steam-jet system they are incapable of mutual adjustment, are considered in their practical application in Section V., having in view the theoretical conditions set out in Section II.

Comparative Tests.

The results or figures which are obtainable of running trials or data as to consumption and cost over lengthy periods with liquid fuel, are of very little use for comparative purposes except for those deductions which may be made speculatively; and yet it is one of the first details for which an engineer asks who is interested in a contemplated conversion from coal to oil burning. A little reflection will show that even on the same railway system trial conditions vary so greatly that it is not possible to depend with any degree of finality upon results so obtained. Given two locomotives of identical types, built by the same maker, equally fitted in all respects, and driven by the same men, it is well known that the steaming qualities and behaviour may be quite distinct for each case. Even when the average is taken over the same road, with regular loads and at corresponding periods of the year, the time allowed for safe comparison should not be less than three months. It would not be at all profitable to the reader to devote much space here to the recital of records, but a few will be given for such information as they afford. As a matter of fact, results based upon costs do not come within the scope of this work, which is confined to the practical application of the principles involved for the one part and evaporative efficiency for the other. The question of cost is bound up with the cost of other fuels, as will be clear from the case of the Mexican Railway, with no coal, and oilfields on their routes, and the Great Eastern Railway, England, with cheap and abundant coal and no oil. Nevertheless the principles of burning liquid fuel are identical in both cases, although the economic question is quite another matter.

The factors which prove so variable on all kinds of trials are such as—the direction and force of the wind; the condition of the track, that is to say, greasy or dry rails; curves and gradients; stoppages; the condition of the rolling stock; the humidity of the atmosphere, etc. It is not necessary to trespass on the particular province of the locomotive engineer by emphasising the effects of these factors, which

are all fully recognised, but it may not be inopportune to say a word here as to the basis on which comparisons are made.

The basis taken for all stationary boiler tests is that of the quantity of water evaporated per pound or per kilogram of fuel and the boiler efficiency as that of the ratio of heat units contained in the fuel to those utilised in effective evaporation. This is what all locomotive trials should be resolved into, but a basis much less stable, for the reasons just given, is usually preferred. This basis is that of either engine miles, train miles, or ton miles, and very often this basis is accepted without any proper regard to the time actually taken for the several journeys or the speed. In short, too many things are taken for granted and too little attention given to actual duty performed. At any rate, whatever other comparisons are made or may be necessary, the fundamentals of fuel consumed and water evaporated should not be lost sight of.

It must be self-evident that the records of consumption per ton mile or per train mile, for example, form no basis of comparison between a railway with a practically level track, such as that of the Great Eastern Railway, England, and those of the Peruvian Railways, which rise 15,000 feet in 150 miles. Between these two extremes there is every variety of gradient and track.

The following figures, however, may serve some useful purpose.

On the Mexican Railway the coal and oil fuel position from 1910 to 1912 inclusive was as given in Table 10.

The figures in this table deal only with the quantities of oil consumed per train kilometre, but no information is given as to whether the train kilometre in 1912, when oil only was used, represented heavier, lighter, or equal loads compared with those of 1910, when coal was employed. Assuming that the loads were equal, then the ratio of 61·91 pounds to 91·03 pounds shows no real saving in consumption, because Mexican oil has a calorific value of 18,600 B.Th.U. compared with coal of, say, 14,000 B.Th.U.

This is probably accounted for by inefficient conditions of combustion, the class of burner used being the steam jet.

TABLE 10.—OIL FUEL ON MEXICAN RAILWAY.

Year.	Weight of Fuel in lbs. consumed per Train Kilometre.	Percentage of Fuel.	
		Oil.	Coal.
1910: First half .	91·03	*nil*	100 per cent.
Second half .	91·23	*nil*	100 „
1911: First half .	86·41	22 per cent.	78 „
Second half .	66·09	80 „	20 „
1912: First half .	63·37	92 „	8 „
Second half .	61·91	100 „	*nil*

In Table 11 is given a summary of a series of trials on the Mexican Railway, between the steam-jet system and the pressure-jet system, under approximately equal conditions so far as the data goes. This record shows a marked superiority for the pressure-jet system. No reference is made to evaporative efficiency.

Table 12 comprises a liquid fuel and coal test, giving the comparative consumptions between coal and oil, and also the economy in point of cost. This test was carried out on one of the railways in South America.

TABLE 11.—OIL-BURNING TRIALS ON LOCOMOTIVES—MEXICO.

Cylinder 15¼ inches × 22 inches.

	Pressure Burner (Wallsend Type).								Steam Burner (Modern Type).					
	Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.		Run No. 6.		Run No. 7.	
	Out.	In.	Out.	In.	Out.	In.	Out.	In.	Out.	In.	Out.	In.	Out.	In.
1. Date of test	9th Sept.		11th Sept.		12th Sept.		12th Sept.		13th Sept.		14th Sept.		15th Sept.	
2. Number of cars in train	5	—	6	10	5	—	5	—	5	6	5	3	5	—
3. Type of cars	Bx cars		Bx cars		1 Tank 4 Bx cars		1 Tank 3 Bx cars		Bx cars		Bx cars		Bx cars	
4. Total tare in tons	76·24	—	90·29	150·5	77·62	—	77·28	—	73·24	91·32	77·77	44·14	73·89	—
5. Total weight of freight in tons	110·06	—	144·29	—	84·42	—	120·87	—	106·92	—	130·76	73·60	124·40	—
6. Total weight behind engine in tons	186·30	—	234·58	150·5	162·04	—	198·15	—	180·76	91·32	208·53	117·74	198·29	—
7. Total miles covered during test	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	7·76	—
8. Oil used during test in lbs.	286	235	405	418	275	202	301	255	360	343	395	300	404	140
9. Oil used per 1,000 ton miles in lbs.	198	—	222	358	219	—	195	—	256	484	244	328	262	—
10. Oil used per 1,000 ton miles, average for outward runs	—		208		—		—		—		208			
11. Ton miles per lb. of oil	5·05	—	4·49	2·80	4·57	—	5·10	—	3·89	2·06	4·09	3·04	3·80	—
12. Ton miles per lb. of oil, average for outward runs	—		4·80		—		—		—		3·92		—	
13. Average steam pressure	118	122	115	110	120	120	120	120	112	110	112	110	110	120
14. Drop in steam pressure taking gradient at pump-house	8 lbs.		8 lbs.		5 lbs.		5 lbs.		20·25 lbs.		15 lbs.		15 lbs.	
15. Drop in steam pressure taking gradient outward run	—		10		—		—		25 lbs.					
16. Time on run (non-stop) in minutes	41	30	47	48	36	29	35	28	50	35	37	38	34	28

TABLE 12.—LIQUID FUEL AND COAL TEST (SOUTH AMERICAN RAILWAY).

GOODS TRAIN THREE TRIPS AND THREE TRIPS OIL (SUPERHEATER ENGINES) UNIFORM LOADS.

Engine No.	Burning.	Total Kilometres.		Total Kilos Consumed.	Consumption in Kilos. per		Cost in cents Gold per		Remarks.
		Engine.	Decatons.		Engine Kilom.	Decaton Kilom.	Engine Kilom.	Decaton Kilom.	
1	Coal	576	55·080	13·550	23·52	0·246	22·471	0·2350	With the cost of coal is included one cubic metre of firewood for lighting up her trip, at $1.60 per cubic metre.
2	Oil	598	55·440	9·604	16·61	0·173	18·520	0·1928	
Difference in favour of	Coal								Stores prices per 1,000 kilos of coal, $9.20; oil, $11.15: *difference*, $1.95. *N.B.*—$5·04 = £1.
	Oil			3·946	6·91	0·073	3·951	0·0422	
	Saving			—	29·379%	29·674%	17·58%	17·97%	

NOTE.—*These trial trips were run with a uniform load of empties* 204 *axles,* 102 *decatons, except that on one trip engine No.* 2 *had* 208 *axles, or* 104 *decatons.*

SECTION V

DESCRIPTION OF BURNERS; FIREBOX ARRANGEMENTS; REGULATION OF DRAUGHT

BURNERS.

IT is the intention in this section to consider the behaviour of the atomised oil within the furnace, and the extent to which the actual form of the flame affects the efficiency of combustion. Both steam-jet and pressure-jet burners have been described and illustrated, at least so far as appertains to the method of atomisation and the special claims to consideration which each embodies. For the moment, therefore, these special claims may be considered to stand quite apart from the point now about to be put forward, as in both cases the object is the same, namely, to break up the oil and introduce it into the furnace in the form best suited for attaining perfect combustion. In this respect both systems stand on common ground, the *pros* and *contras* for the adoption of either the one or the other being dependent on characteristics already compared, and which are beside the question of the nature of the flame inside the firebox. This statement, of course, is made with certain reservations—for example, the point of combustion of the oil atomised by the steam-jet is advanced further within the furnace than is the case under the pressure-jet system. Generally speaking, however, the lines to be followed in furnace arrangements or firebox adaptations are more or less equally applicable in each case.

By reference to the illustrations of steam-jet burners it will be seen that the oil can be introduced practically in any form or shape desired; that is to say, a burner can be so designed as to give a circular spray, a wide and flat spray,

or a spray in the form arranged in Holden's burner, in which seven distinct injections are made. The pressure-jet burner, on the other hand, is confined to the discharge of the oil from a central and round hole in the nozzle, in order to accomplish satisfactory atomisation. This is made more effective by imparting to the oil a revolving motion as it leaves the nozzle, by causing it to pass around a spiral, or through holes in a diaphragm, just prior to the point of discharge. This spiralised motion brings the particles of the oil into more intimate contact with the incoming air, and so assists combustion.

Having thus described the manner in which oil can be injected into the furnace, it now remains to consider the actual form the atomised oil should take under varying conditions.

By reference to the analogy insisted upon in Section II. between the burning of bituminous coal and the burning of oil, the first point upon which to be absolutely certain is that the oil flame entirely fills the space allotted for initial combustion, just as coal is laid evenly over and entirely covers the firebars. The ideal furnace arrangement in this respect for oil burning is undoubtedly that of the cylindrical type as employed in Lancashire, Galloway, or marine cylindrical boilers. Such a furnace is illustrated in Fig. 19, which also shows the oil jet of conical form impinging upon the brick lining all around and entirely filling the area of the furnace tube.

The second essential condition is that the air admission should be behind the flame, and that the air should have an equal pressure all around the nozzle of the burner, just as air is admitted below the firebars in coal firing with an equal pressure at all points of the fire-grate area. It must now be obvious that in order successfully to accomplish this air cannot be admitted at any irregular opening, nor at one side only or below the centre of combustion. In such a case the draught would pull from the direction of the air admission and cause the flame to be diverted. In any application of oil burning to locomotives the two conditions just enumerated must always be aimed at, and any claims

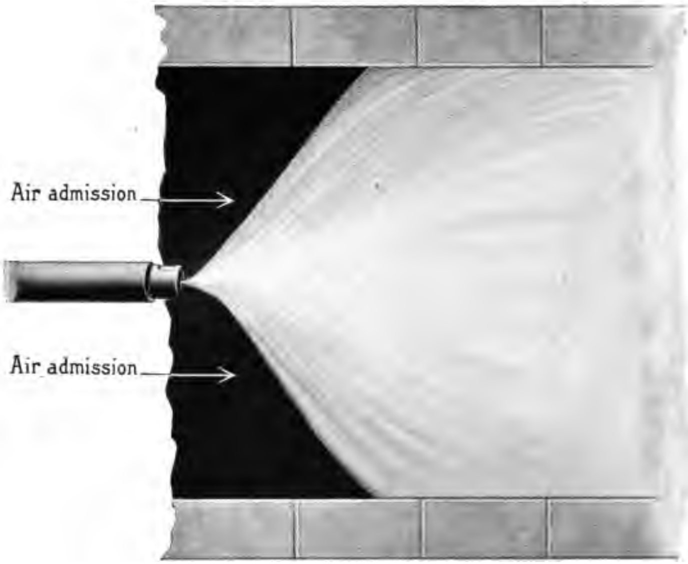


FIG. 19.—Ideal Combustion Furnace.

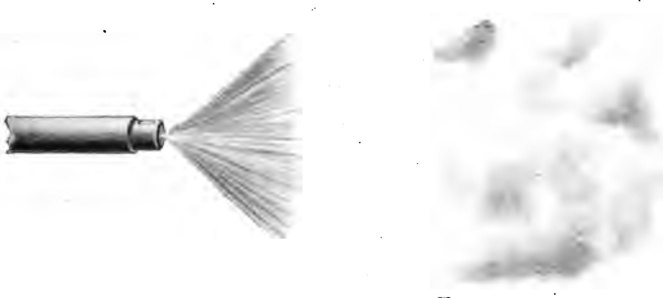


FIG. 20.—Combustion in Open Air.

which are made on behalf of any system which does not embody these conditions are not likely to be fulfilled.

The writer is aware that this is striking something like a new note in respect of oil burning on locomotives, but it is the object herein to point out why the existing methods do not give results in any way commensurate with those readily obtained on stationary boilers. Hence it is necessary to start from ideal conditions, that is to say, conditions which embody all the theoretical requirements, and to evolve from them, if possible, the nearest practicable approximation. The difficulties which exist in the case of locomotives, and which have to be overcome, are the irregularities of duty, wide range of draught variations, and divers forms of fireboxes. It is these which make the problems so distinct from most other types of boilers.

An ideal furnace, therefore, is one in which the system is so arranged as to maintain perfect combustion from the minimum consumption of oil to the maximum, responding immediately, and as far as possible automatically, to every demand made upon it.

The condition farthest removed from the ideal is when oil is burnt in the open air. If any ordinary oil-fuel burner is operated in the open air, the effect produced will be that shown in Fig. 20. The oil will burn with a white hot flame for a few feet from the nozzle, but before combustion can be completed the air cools the hydrocarbon gases, and the unconsumed portion passes away as dense black smoke. This is exactly what happens inside the firebox when cold air is admitted in excessive quantity, and the experiment clearly indicates the absolute necessity of keeping up a high temperature around the flame. It is with this object that brick arches and brick linings are indispensable in oil-fired fireboxes.

Another departure from ideal conditions is when the oil spray is not sufficiently spread out to fill the firebox area. If the jet is thrown too far into the furnace through defective burner design, or if it is " drawn out " too much by excessive draught, considerable space will be left all around the flame, where no combustion is taking place.

The space so formed allows the passage of free unconsumed air, at a low temperature, directly into and through the combustion chamber, having the effect of cooling the brickwork, gases, and heating surfaces of the boiler. This condition is represented in Fig. 21. This frequently occurs in locomotive practice, and it has often puzzled enginemen to account for poor steaming qualities when the full capacity of oil has been turned on with the strongest draught going at the same time. Perfect combustion would appear to be indicated by the absence of smoke, but what really is taking place is the cooling effect of excessive air and the heated gases passing away to the outer air at a very high temperature. With coal firing it is almost impossible to pull too much air through the firebars and bed of coal without increased effective combustion, but it must not be forgotten that the resistance to the air draught in that case is enormously higher than with the light particles of oil. The reference above is to excessive air supply in contradistinction to the exact quantity required for additional fuel consumption. With oil fuel, therefore, some means has to be provided for avoiding the effect shown in Fig. 21, and this, so far as it does not relate to defective burner design, will be treated under the heading "Regulation of Draught."

A simple method of ascertaining the angle of throw of a pressure burner is to attach it to a hand pump and force water through it at about 200 pounds pressure. This will give an indication of the degree of atomisation and the angle at which the spray leaves the nozzle. An effective burner should spray at an angle between 70 degrees and 90 degrees; a burner throwing the spray at 40 degrees or 50 degrees will concentrate the oil too much in the centre. Steam jets can only be effectively tested under working conditions.

Fireboxes.

The following examples of locomotive fireboxes have been selected with the object of illustrating how far they comply with the conditions laid down for perfect combustion, and in what respects they are deficient. With regard to actual

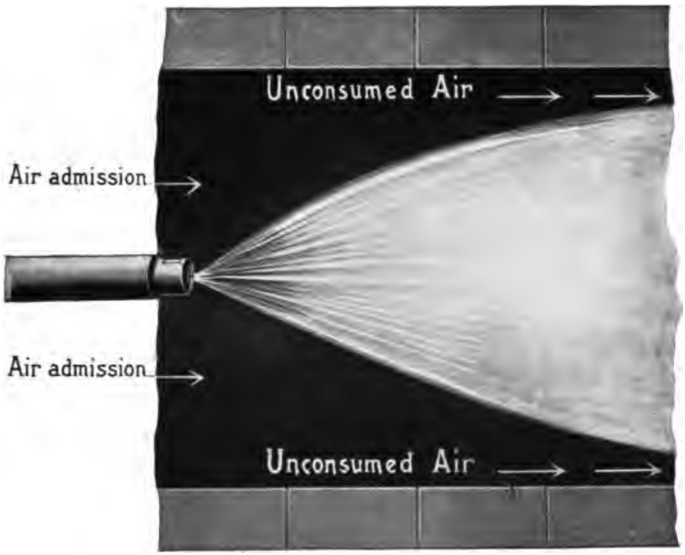


FIG. 21.—Defective Combustion.

performance, it is not possible to obtain dependable figures of boiler efficiency or pounds of water evaporated per pound of fuel over any considerable period. Records from several sources show an average of 11 to 1 for evaporation, which is not satisfactory in comparison with 16 to 1 (from and at 212° F.) obtainable with stationary boilers. No doubt the form of brickwork and method of air admission are responsible to a much greater extent than is the type of atomiser employed.

Fig. 22 is a section of the firebox arrangement of the oil-burning locomotives of the Mexican Railway. The burner,

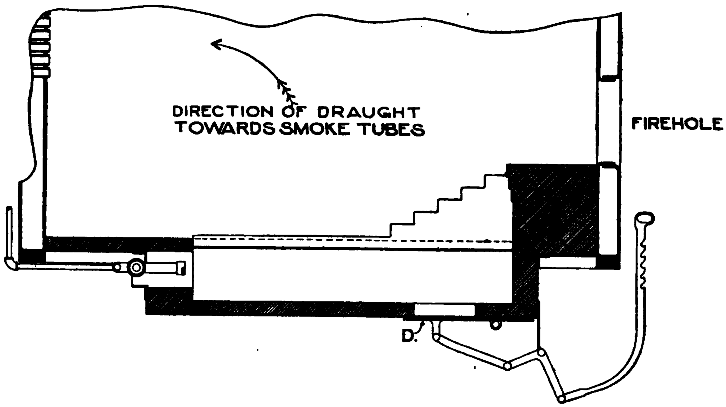


FIG. 22.—Mexican Railway Firebox.

of the steam-jet type, is placed below the foundation ring, in the ashpan space, at the forward end. The extent of the brick lining is shown, the section at the back end being 18 inches in thickness. A very noticeable feature is the entire absence of the usual arch, and there is no brick lining provided for protection of the firehole door. Air is admitted around the burner, and by supplementary air holes on both sides of but underneath the burner, and also by means of an opening at the bottom of the ashpan at the back end, which is controlled by the damper *D*. It will be observed that practically the whole of the heating surface of the firebox has been retained with the exception of the small portion at the back end and sides.

The whole of the firebox forms the combustion chamber, but combustion is effected principally at the back end, the steam jet dispersing the oil in a widening flame from the nozzle to the solid brickwork marked *B*. The firebox is an exceptionally long one, being 9 feet between the inside plates. Hence the completion of combustion, which always occurs well forward with steam-jet burners, takes place at a considerable distance from the nozzle, and the brickwork is raised sufficiently high at that point to prevent direct impingement of flame on the metal plates. It is at that point where supplementary air is admitted from below to complete the combustion, but the air enters at the temperature of the atmosphere only. The air which is admitted at the burner end becomes heated by contact with the hot brickwork around the burner, but this chamber is only 9 inches in length.

The points which call for comment are as follows :—

The direction of draught is from the air openings towards the smoke tubes, indicated by the bent arrow, and in this case, owing to the absence of an arch, it is a direct pull. It would appear, therefore, that the flame cannot possibly fill the whole of the combustion area, that it must double back upon itself, striking, not upwards, but in a direct line for the smoke tubes. A very large proportion of the firebox heating surfaces, such as the side plates and nearly the whole of the crown plate, gets no direct impact of the flame, and for that reason cannot be effective for steam-raising. Turning to the method of air admission, unless the flame fills the entire lower portion of the ashpan, which it cannot possibly do, a considerable quantity of excess cold air must be admitted, which serves no useful purpose, but which, on the contrary, must have a cooling effect on the heating surfaces and on the gases of combustion as they pass away from the back end to the smoke tubes. In any case there is the objection that air does not surround the flame, the top part being without any effective air supply.

The arrangement, therefore, does not appear to be one from which good evaporative results are to be expected. Oil on this system is very plentiful and very cheap, and the

results obtained from a calorific point of view do not seem to be better than those obtained with coal. (See Table 10.) The Secretary of the Mexican Railway, Mr. B. E. Holloway, in his paper on "The Use of Oil Fuel on Railways," referring to the firebox arrangements just described, says "there are many types of burner on the market, all no doubt having their special merits, but I think it may be safely stated that successful firing does not depend so much on the burner itself as the manner in which it is used. What

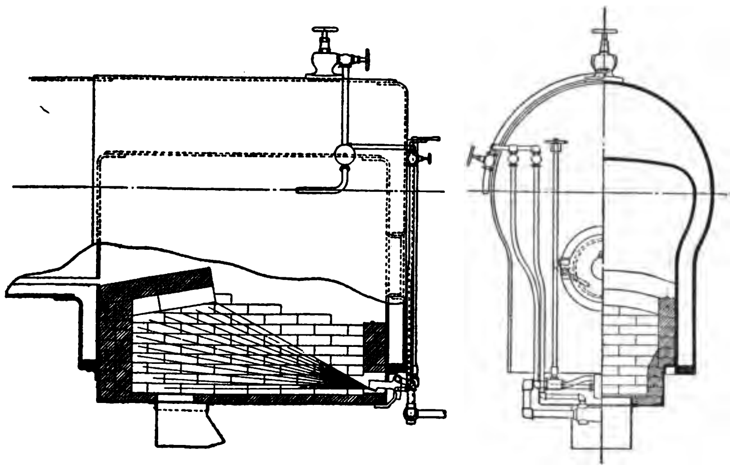


FIG. 23.—Baldwin Locomotive Company's Firebox.

appears to be the chief necessity is that the burner should be simple, fitted in such a manner that the proper proportions of steam and oil can be used, and that the fireman shall keep a constant watch on his steam gauge and smoke stack." (See *The Railway News*, 4th January, 1913.)

Mr. Holloway makes no reference to the firebox conditions, but lays emphasis on the manipulation of the burner only. The deduction to be drawn is that the burner may be for its class entirely satisfactory, but that the manipulation referred to is not so much that of the burner as the endeavour on the part of the fireman to adapt a number of conflicting conditions which vary, one or all of them, from moment to moment.

The fireboxes of the Southern Pacific Railway, U.S.A., are arranged in a manner almost identical with those of the Mexican Railway.

Fig. 23 shows the firebox arrangement of the Baldwin Locomotive Company, U.S.A. It differs from the preceding case in one or two important details. The burner, which is of the flat-flame type, is placed at the back end of the firebox; another flame is directed towards the tube sheet. The brickwork, however, includes the usual arch at the forward end, and the space so enclosed forms the combustion chamber. Air is admitted around the burner, and also through two rectangular openings, 12 inches by 8 inches, controlled by dampers. A very considerable area of the lower portion of the water space is blocked out by brick linings, but the direction of draught is deflected by the arch, and this will have the effect of throwing the flame against the exposed parts of the side and crown plates before it passes through to the smoke tubes.

The air in entering around the burner is considerably heated, and in being drawn upwards by the draught it passes over the heated face of the back brick lining, thereby itself reaching a high temperature, ultimately meeting the flame as it passes over the edge of the arch. The arrangement is altogether superior to that depicted in Fig. 22, and the liability to the excessive air admission is very much lessened. The size of the firebox inside is 5 feet 6 inches long by 2 feet 10 inches wide, including the brick lining.

The burner used is designed with a flat and wide horizontal lip, in order to spread the flame almost entirely over the bottom of the ashpan, thus reproducing as nearly as possible the conditions obtaining under coal firing. (See Fig. 1.) The width of the burner lip is determined by allowing 1 inch for every 100 square inches of cylinder area.

The difference between the effect of the flat form of oil injection and that of the circular or conical spray will be apparent by comparing Fig. 24 with Fig. 19.

Fig. 25 illustrates the firebox in use on the Los Angeles and Tehuantepec Railways, U.S.A. The steam-jet burner is placed at the back end as in Fig. 23, but there is no pro-

Fig. 24.—Flat Form of Oil Flame.

tective brick lining against the plate at that end and therefore nothing to warm up the cold air which enters around the burner. The arch is much heavier, and brought further back into the firebox, leaving a space between its wall and the front tube plate. Such an arrangement is only possible with very long fireboxes, and is interesting as a tacit admission that the theoretical value of the fuel has not yet been obtained on locomotives. This particular type possesses the disadvantages of the two others just described as regards liability to air leakage past the combustion chamber. It really seems in some cases to be an open invitation for excess

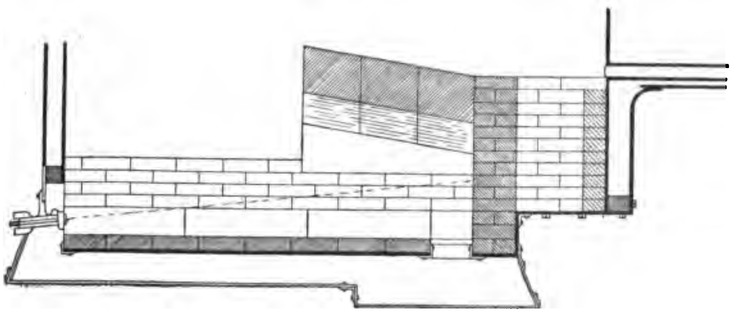


FIG. 25.—Firebox of Los Angeles and Tehuantepec Railways.

air to enter, just as if several holes were left purposely open in the bed of a coal-fired engine. The analogy between these two forms of firing may now be more clearly seen and appreciated. Differences in brickwork arrangements, methods of air admission, position of burners, etc., may each produce certain modifications tending to improve combustion, but relatively to the main object they are only compromises. Indeed, it is an open question whether the steam-jet system does not necessitate such conditions for combustion that complete compliance therewith is impossible within a locomotive firebox.

In the system devised by Mr. Holden, of the Great Eastern Railway, England, the ideal conditions of burning oil fuel by means of the steam atomiser were very nearly attained. But this was because his system was one for combined coal and oil firing, and not for oil firing only. He laid it down as

a *sine qua non* that the use of oil fuel should in no way require modifications to the interior of the firebox, which would prevent an immediate return to coal firing if required; in other words, coal firing was the first consideration and oil only supplementary to it. In thus combining the two in the firebox arrangement shown in Fig. 3 he was able to reduce the thickness of his coal on the firebars, thus reducing the resistance to the passage of air through it, in fact allowing sufficient excess air to pass freely through to consume the oil. The air is thus introduced *evenly over the entire grate area;* its regulation is more accurately adjustable, and by the retention of the arch and air deflector above the firehole the proved conditions of efficiency are not altered in any way. As an oil-burning system, however, it cannot be considered on independent merits, but as a preventative of cold and excessive air admission the combination should give higher results in relation to the number of heat units liberated than either coal or oil used separately.

Following the foregoing lines, experiments have been made by retaining the firebars and covering them with broken bricks to a depth of some inches, in order to produce a similar air admission effect as through a bed of live coal. The effect, however, is not the same, as the bricks melt together and tend to the formation of carbon deposit.

The use of the air deflector arch over the firehole in coal-fired locomotives provides a very strong example of the absolute necessity of preventing cold or excess air from being drawn into the firebox without doing useful work. It is another detail which, if applied with logical inference, proves the necessity of following the lines of successful coal burning.

The application of the pressure-jet system to locomotives has not yet had any very extended trial. The results given in Table 11 appear to be due to the higher heating effect of the oil when steam is absent and the earlier combustion in the firebox. So far as excess air is concerned, the liability is much the same as with the steam-jet system, where the firebox arrangements are practically identical. For the reasons already given, it is more applicable to small fireboxes, but the apparatus involved might not be easy to dispose in

a very limited space. In Figs. 13 and 13A an arrangement of firebox and dampers is shown on the Wallsend-Howden system. The air is admitted below the area of combustion and is regulated by the dampers shown. The air admission holes are circular, about 2 inches internal diameter, and they break up the air into a number of jets instead of introducing it in a solid gust. These air holes get very hot and the broken air is thus effectively heated in its passage. The best results have been obtained with the Wallsend-Howden

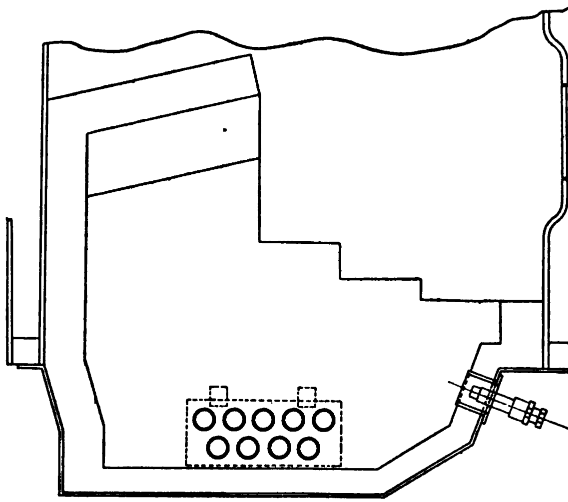


FIG. 26.—Wallsend-Howden Side Damper Arrangement.

system when the air admission has been arranged at each side of the ashpan in the centre and immediately below the foundation ring. The end dampers and air admission holes in the bottom of the ashpan have thus been superseded and better regulation and less excess air have been found to result. The damper arrangement is shown in Fig. 26.

Fig. 27 shows the firebox of some of the heavy type passenger locomotives on the Central Railway, Brazil. These fireboxes are of large dimensions, being 7 feet in length and 6 feet in width inside. They are furnished with two fireholes for coal firing, and the oil-burning fixtures include five burners, three being placed at the front end and two at

the back. The arch, which is represented by dotted lines in the end elevation, is of too wide a span, both from the points of view of maintenance and combustion. In such exceptional cases it would be better to build two arches with

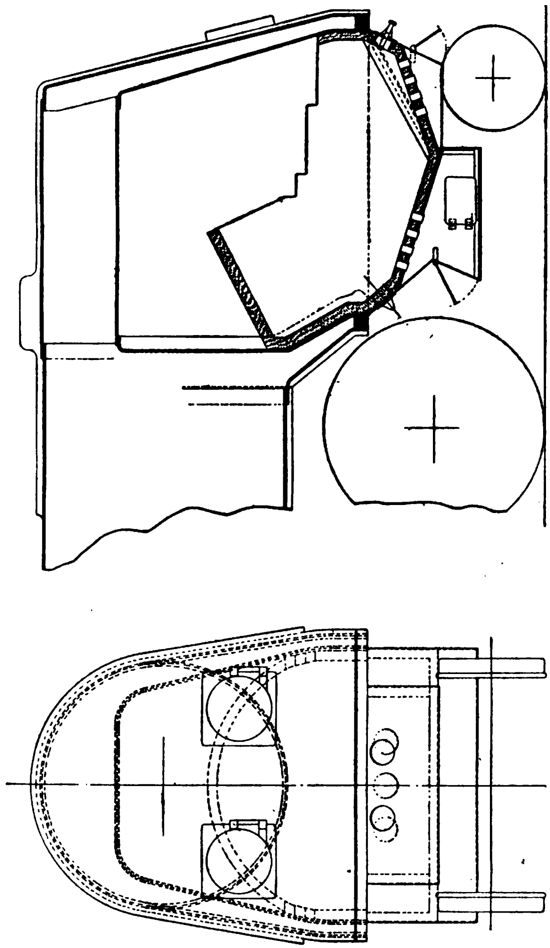


FIG. 27.—Brazil Central Railway Firebox.

a division wall between in place of one of 6 feet span. The usual air admission and damper arrangements are employed.

Some extended experiments are about to be made with a new design of firebox brickwork and air admission devised

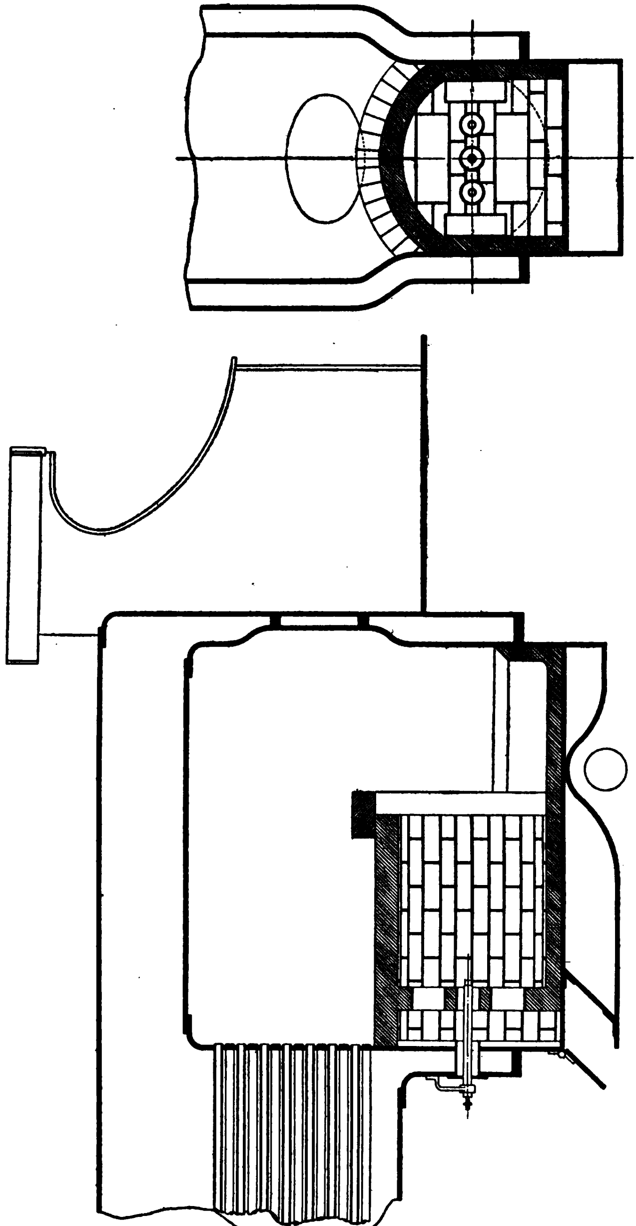


FIG. 28.—Author's Firebox Arrangement.

by the writer and illustrated in Figs. 28 and 29. These modifications have been made for use more especially with the pressure-jet system, but the principles embodied would also apply to the steam-jet system, provided a steam-jet atomiser could be designed to produce a flame in the form shown in Fig. 19. The point of maximum combustion with the steam-jet atomiser is usually so far delayed that the object of the special form of arch might be frustrated.

Fig. 28 shows an ordinary type of firebox, into which is built a cylindrical, or nearly cylindrical, chamber of firebrick. About 9 inches from the face of the front sheet is built a firebrick wall, 4½ inches in thickness, and extending over the whole of the sectional area of the brick tube. The space thus formed between the wall and the front sheet acts as an air chamber, cold air being admitted by the ashpan damper in the usual way, but through a perforated metal plate at the base.

The burner or burners are introduced through the water space and air chamber to a point just flush with the inside face of the wall. No air is admitted around the burners where they pass through the water space, but in the wall openings are made by means of cast-iron frames, circular and concentric with each burner and rectangular with all of them.

The form of the cylindrical chamber or modified form of arch takes the form of the oil spray, and the avoidance of flat brickwork and right-angled corners prevents the possibility of the passage of unconsumed and cold air. Briefly, this arrangement may be described as introducing into the locomotive firebox the cylindrical furnace of the Lancashire type boiler. The length of the cylinder or parallel arch need not be more than 4 feet from the front sheet to the brick corbel, and within that distance perfect combustion will take place with the pressure-jet system. The actual size and area of the brick tube can be designed to suit the capacity of the locomotive.

The great advantage of this design is that the wall becomes white hot, and the air enters the furnace at a very high temperature.

Further, it enters on every side of the oil spray, and follows more nearly than any other form of air admission the conditions of coal firing.

With the pressure system and the early ignition of the gases there is no necessity to introduce supplementary air at a later point in the combustion chamber, as perfect combustion takes place at once. Any excess air which may be carried forward remains at the temperature of the furnace, and therefore has no cooling effect on the side and crown plates, smoke tubes, or products of combustion. The temperature of the furnace is therefore maintained and higher efficiency results.

With the foregoing arrangement some small percentage of the heating surface in the firebox has to be sacrificed, and in order to avoid the effect known as "cold feet" the portion of the water space in the front plate covered by the air chamber must be lagged inside with thin fireclay slabs or asbestos. In the portions of the brick lining outside the cylinder, spaces may be left by omitting alternate bricks known as honey-combing, so as to retain as much as possible of that heating surface. The floor of the ashpan is left in the form of an arc, and not entirely flat.

The direction of the draught will cause the flames to impinge on all plates, the object of the corbel extension being to throw the flames against the crown plate. The form of the area above the cylindrical tube will ensure a more even distribution of the heat through the smoke tubes, and as there is no possibility of cold air being drawn in, the liability to leaky tubes disappears.

Fig. 29 is a modified arrangement of Fig. 28, the wall forming the air chamber being omitted. In its place the air is conducted up each side of the brick tube, and a portion has to be taken from outside through the ferrules surrounding the burners. This type, therefore, is not so good as the other, but in very short fireboxes it might be a more convenient form than the one in which the wall is employed.

In both these cases it will be noticed that the cylindrical tube and burners are at the forward end only. This is the only possible position to ensure effective heating of all the

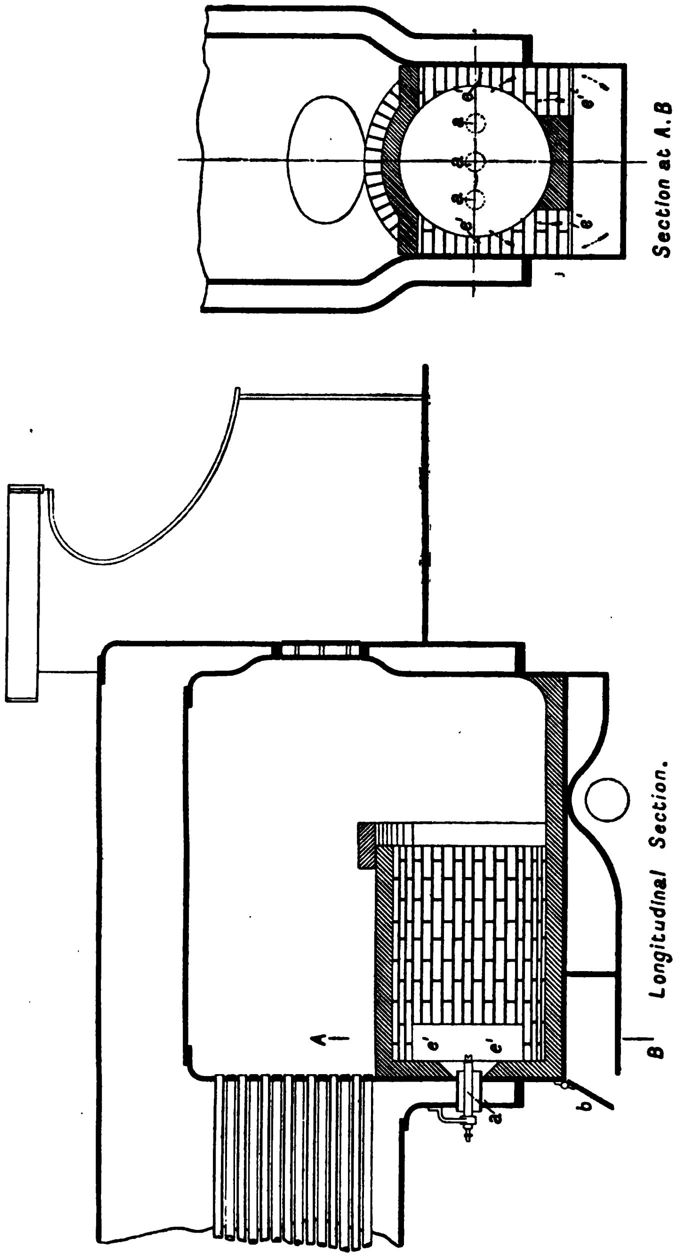


FIG. 29.—Author's Firebox Arrangement.

surfaces. The same arrangement placed at the back end would result in the heat of combustion being drawn directly into the smoke tubes without any appreciable effect on the firebox heating surfaces.

Another reason for the position selected is the effect of retardation of the velocity of the gases of combustion, due to the greater length they have to travel, and also due to the considerable expansion they undergo on issuing from the cylindrical tube.

It is not proposed to publish results here as to the efficiency of this particular device, because for obvious reasons the types and conditions of locomotives vary so widely, but the writer will be glad to give any further information by correspondence to those interested.

Draught Regulation.

While in the majority of firebox adaptations to burn liquid fuel the knowledge and experience gained with successful coal firing has been largely overlooked, the original methods of draught regulation have been retained with equally unsatisfactory results. A cursory examination of the illustrations of firebox arrangements given earlier in this section will show that the primitive ashpan damper has been retained in its unaltered form and position. The method of operating the damper is that of a simple lever connected by a rod to a hand lever in the cab, the hand lever being provided with three or four notches for engagement with a holding catch. (See Fig. 22.) The effect of opening the damper is therefore to expose a very considerable area for air admission which is not greatly affected by the differences in the adjustments provided. Under the most intelligent operation by the fireman the arrangement falls short of effective regulation of air supply in the case of oil fuel, but answers well enough for coal firing. This is especially the case when it is compared with the accurate regulation possible and necessary with the air distributors on stationary boiler installations. This is due to the fact that the smallest opening of the locomotive damper exposes the whole area

of air admission and adds the area of the sides formed by the angle of the damper plate. In the first place, therefore, the damper plate should be covered in at the sides and the lever controlling the damper should have a wide movement for a comparatively small movement of the damper.

This might of course be accomplished by means of a screw movement of the lever in the cab, but there may be objections to such an arrangement. At any rate, it should be made impossible for the fireman to swing the damper wide open in place of attempting proper adjustment of it. The suggestion to box in the damper plate at the sides is to present a regular rectangular opening at each point of adjustment and if possible to graduate it at the lever end for certain definite duties. Up to the present this question of damper control has been left to the locomotive engineer to fix up in any convenient mechanical manner, but in view of the vital importance of air admission regulation on stationary boilers, and its even more serious aspect on locomotive oil-burning installations, the control must be in the nature of some device which will practically obviate excessive air admission by the fireman. What is wanted is a positive control which will leave the damper plate at any angle or point, and this can best be effected by a screw movement. A screw movement control would also have the advantage of being able to close the damper tightly, a *desideratum* not characteristic of the usual method. Greater efficiency would thus result if some such approximation to stationary boiler practice could be introduced.

As draught is caused by the discharge of exhaust steam into the chimney, it follows that every variation of velocity or quantity of exhaust steam produces a corresponding variation in the degree of vacuum created in the firebox. This irregularity of draught production does not always coincide with the necessity for increased or decreased combustion, as the case may be, nor are the variations proportionate to the quantity of air required at the moment. Within certain limits, however, dependent upon the relation between the exhaust nozzle, smokebox conditions and its cubical capacity, number and arrangement of ashpan

dampers, etc., the rate of combustion is mainly dependent upon the exhaust steam effect. It is therefore a short step to the natural deduction that the correct method of regulating the draught should be by regulating the cause of it. It was stated in Section II. that the intensity of draught required for oil burning, or in other words the degree of vacuum in the firebox, is only about one-fifth of that necessary with coal, because the chief resistance to draught in coal firing is the thickness of the bed of coal on the firebars and the small interstices through which air has to pass. On the other hand, it requires about 24 pounds of air to burn 1 pound of oil as compared with about 18 pounds of air for 1 pound of coal, so that while the resistance to the passage of air is much less with oil the quantity required is greater weight for weight.

Without pressing the argument further, it may be assumed that one-quarter to one-third of the firebox vacuum necessary with coal will suffice for oil, and conversely from three to four times too much air for oil will be pulled through the firebox if the conditions for coal burning are left unchanged. The determining factor of this draught production is the diameter and position of the exhaust nozzle in the smokebox.

With regard to the diameter, the exhaust nozzle in engines having cylinders of 16 inches diameter and upwards will be between 4½ inches and 5½ inches. This diameter can therefore be at once increased by 1 inch or more until it is determined experimentally with what lowest vacuum effect combustion can be maintained.

The position of the blast pipe may vary from the bottom row of tubes up to the chimney base, but for oil burning, in which the gases have to be retarded, the correct position should be that in which equal heating effect will be induced in all the tubes. Beyond these indications of the essential alterations necessary with oil fuel, it is not proposed to go. Each case will require different treatment as regards detailed adjustments, and, after all, the locomotive must be accepted as it stands. The primary feature is the absolute necessity of reducing the vacuum created in the firebox.

The extent of the reduction having been determined, the

proper and most efficient method of regulating the influx of air is by varying the mean diameter of the exhaust nozzle more or less as required. It is obvious that, if the chimney outlet were entirely closed, the fact of the ashpan damper being more or less open would have no effect on the combustion chamber, as no air would pass. Similarly, if the entire regulation of draught were attempted by means of the ashpan damper only, fine adjustments would be quite impossible, because the vacuum in the firebox would cause excess air to be drawn through. The remedy therefore is the use of a variable exhaust nozzle, so designed as to be under rapid control by the enginemen, and used by them for draught regulation under all variations of load, in preference to ineffective regulation by the damper. The damper should also be capable of accurate adjustment as described, but its fixed position will be determined from time to time in accordance with the limits of operation of the variable blast. Both methods of regulation are necessary, but the variable regulation from minute to minute as the load varies should be effected solely by nozzle control.

The types and designs of variable exhaust nozzles are legion, but it is doubtful if the subject has been carefully studied from the oil fuel standpoint. Emphasis has always been laid upon damper control, which is the most inefficient method, because it deals with the wrong end of the process. The object is to get rid of the expanded gases of combustion as they are formed and at the rate at which they are formed. The admission of the right quantity of air to continue combustion then becomes automatic, as there is no resistance to its entry into the firebox. A very little inductive effect from the exhaust nozzle will bring about a perfect rate of discharge from the smokebox, and that is where the regulation must take place. It is hardly permissible to call the chimney a smokebox detail, but as ample discharge space from the tubes is essential, not only should the smokebox be of large capacity but the diameter of the chimney should be considerably increased. Retardation of flow of the gases of combustion must not be confused with back pressure, which prevents combustion.

The foregoing points may be summarised as follows, viz. :—

1. Main draught regulation by means of variable exhaust nozzle.

2. Auxiliary draught regulation by means of damper accurately adjustable.

3. As large a smokebox capacity as possible.

4. Position of blast pipe to give equal distribution of gases in all tubes.

5. Enlargement of chimney diameter to give double sectional area, where possible.

6. Use of cap on chimney to save loss of heat when running on down grade or standing.

In following the reasons just given for utilising to the utmost extent possible the whole of the firebox, smoke-tube, and smokebox areas it must not be forgotten that in addition to the air introduced for combustion there are the gases generated from the oil. These take up a much larger area with oil burning than with coal, and air also expands greatly when heated. The increase in volume of air by elevation of temperature may be determined by the following formula :—

$$\frac{\text{Given temperature} + 461}{62 + 461}$$

where the initial temperature of the air is 62° F.

The increase in the diameter of the exhaust nozzle, and possibly in the blast pipe if not large enough at the aperture, with the consequent greater freedom of discharge of the exhaust steam, results in a freer movement of the locomotive and more power, as every pound of back pressure saved is equivalent to 1 pound added to the pressure of steam in the boiler.

Regulation of Oil Supply to Furnace.

In the steam-jet system the regulation of oil supply is usually effected by means of a valve or valves on the burner, the operation of which increases or decreases the opening through which the oil and steam respectively pass. The maximum economic capacity, or effective atomisation limit,

per burner is about 600 pounds of oil per hour, and therefore any greater quantity necessitates more than one burner.

In the pressure-jet system the same method of regulation is adopted, but there is no steam valve. The oil capacity per burner should not exceed 450 pounds per hour, and hence two or more burners must be employed for a higher consumption.

In actual operation the admission of the exact quantity of oil or oil and steam is a matter of experience, and follows much the same method as the dual regulation of air and petrol in automobile control. In a short time the engineman will know intuitively just what proportions and quantities are necessary.

In the Wallsend-Howden system the capacities of each burner can be accurately determined by the size of diaphragm and nozzle used, and this arrangement tends to economy in oil, because as each burner is opened up or shut down a fixed quantity of oil per hour is passed. Hence the control is mainly mechanical and obviates irregular adjustment by the operator. The list of oil capacities for various sizes of diaphragms and nozzles is given in Table 9.

The method lends itself also to better draught regulation, as the adjustment of one main factor is much more simple and satisfactory than where three or four interdependent factors are concerned.

SECTION VI

EVAPORATIVE CAPACITY AND HEATING SURFACE

It is an axiom that the capacity of a locomotive depends upon its firebox. It is therefore most essential that in any arrangement of firebox brick linings, which are absolutely necessary for the proper combustion of oil fuel, as much of the heating surface as possible should be exposed to the flames. A great deal of the extra heating effect of oil fuel will be lost if the area of the heating surface exposed to the fire is much less than with coal firing. In calculating exactly what the heating surface is with coal it is of course necessary to take into account that the portion of the front plate below the arch does not receive much radiant heat and practically no impact. Also this is the case of a considerable area all round the firebars, which are loaded up with 8 or 9 inches of coal more or less dead at the sides. Hence some calculation can be made in the cases of those illustrations of oil-burning fireboxes given in the preceding section of lost effective heating surface compared with the conditions under coal firing.

In an interesting article on the subject of evaporative capacity of a locomotive the *Locomotive Magazine* says :

" The evaporative power of a boiler mainly depends upon the efficiency of its heating surface to transfer the heat from the products of combustion within to the water without. For this it relies on both radiation and contact, from two or three hot masses in the boiler, solid incandescent fuel in the firebox, and flame and hot gases in the tubes. The radiation of heat from the solid fuel is greater than that from the flame, while the hot transparent gases scarcely radiate any heat at all.

" In estimating the heating surface it is customary to take the area of the firebox and tubes in contact with heat on one

side and water on the other, and consider the evaporative power of the boiler as proportionate to the total number of square feet thus found. As all the parts of the heating surface, however, do not possess the same efficiency, the heating surface of the firebox being much more effective than that of the tubes, the result so obtained is misleading in practice; adding length to the tubes does not increase the evaporative efficiency of the boiler nearly so much as increasing the size of the firebox.

"A flat horizontal surface not too far above the fire is considered most favourable, and by being made concave to the fire it has the further advantage of being better able to receive and transmit the radiant heat, of boiling off the matters deposited from the water, and so to some extent preventing formation of scale, and of being stronger and more durable. Next in conductive power come the flat sides of the box, which are made sloping, as they then receive the rays of heat at a more favourable angle, and allow the steam bubbles to escape more freely; they also increase the size of the water space and admit of the use of longer stays at the top of the box where most expansion takes place. The tube plate, although made vertical, owing to the rapid impingement of the flame is as effective as the crown, which is too often hampered by the stays, etc.

"The great superiority of firebox heating surface is owing to the radiant heat being principally given off there, also to the fact that the more violently the flame impinges on a surface the greater the ebullition and consequent formation of steam on the opposite side of that surface.

"The effective area of tubes internally heated is only half their total area, as heat is mostly given off at the upper surface of the tube, owing to the fact that hot gases being light rise, then on giving off their heat they fall and are replaced by hotter ones; also by the difficulty steam has in escaping from the under side of a tube, and the thickness of soot that too often collects inside the tube at the bottom."

The statement that the radiation of heat from the solid fuel is greater than that from the flame applies to incandescent solid coal, but it must not be assumed from this that

oil fuel does not provide solid incandescent fuel; the solidity of a particle of atomised oil is not a very substantial thing, but nevertheless its incandescence is equally or even more effective. The oil flame is that part which results from incandescent fuel, and the hot transparent gases are of the same order as those from coal combustion. As a matter of fact the want of solidity in oil fuel is a point in its favour, because the incandescent particles are carried towards and impinge upon the heating surface more freely. It is in order to retain and direct forward the incandescent particles that refractory brick lining is employed.

A good rule for determining the heating surface of a locomotive boiler is to multiply the length in feet from the smokebox tube plate to the back of the firebox by the diameter of the boiler in feet squared across the front tube plate and take 92 per cent. of the result. This gives the heating surface in square feet. For instance, if the boiler and firebox have a length of 21 feet and a tube plate diameter of 5 feet, then $(5 \text{ feet})^2 \times 21 = 525$ square feet, and 92 per cent. gives 483 square feet effective heating surface.

In order to ascertain the quantity of oil required per hour for a given heating surface, the following formula should be employed, viz. :—

$$\frac{\text{Heating surface in square feet} \times 16}{2{\cdot}2 \times 14}.$$

This gives the quantity of oil per hour for normal evaporation, but in cases or at times where cold feed waters are rapidly injected while the engine is running under normal load the normal quantity will have to be exceeded to maintain steam pressure.

Poor evaporation may result from several causes quite outside the question of fuel efficiency, but these are common with coal firing and need not be enumerated here. The first necessity is impingement of the incandescent particles on the firebox heating surfaces, and this can only be effected in the manner described in the preceding section by the correct form of firebox brickwork, the proper regulation of the draught, and the right type of burner.

Disposition of the Apparatus for the Pressure-Jet System.

In considering this matter reference should be made to Fig. 14, which is typical of any pressure-jet system so far as the arrangement and connection of the several parts are concerned. The first consideration is that of the burners.

The Burners must obviously be located at that part of the furnace which will give the full heating effect on the heating surface of the firebox. This position can only be at the forward end for reasons already described. In that position it will follow the methods adopted in coal firing and retain all the advantages gained from coal firing experience. One

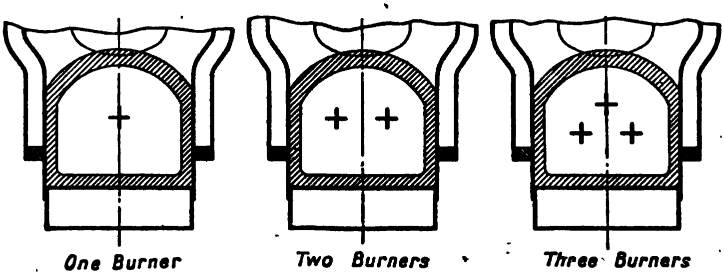


Fig. 30.—Position of Burners.

or more burners may be employed according to capacity and regulation required, and these should be placed as nearly as possible in the centre of the area formed by the arch, sides, and bottom. Fig. 30 shows positions for one, two, or three burners respectively, and in cases where more than three are required the fireboxes will usually be wide enough to accommodate them.

On the inside of the firebox the nozzles of the burners nearest to the side walls or bottom brickwork should be at least 9 inches distant from either side of the brick lining and 10 inches from the firebrick floor measured from the centre of the nozzle. The reason for this spacing is that with a burner having an effective angle of spray of 70 degrees, the oil must not be allowed to strike the brickwork until after it is well alight. The striking distance should therefore never

be less than 15 inches and never much more. A divergence from these conditions will result first in the formation of a deposit of carbon if the burners are too close to the walls or bottom, and secondly in inefficient combustion if the striking distance is too long.

The nozzles of the burners should be about ½ to 1 inch back from the face of the firebrick wall in which they enter, so as to be slightly withdrawn from the fire area.

The Oil-Fuel Pump should be placed either on the cab or on the tender, but in any case as near the oil tank as possible, in order that the oil may enter the pump without loss of temperature. For efficient working of the pump valves the oil should be raised to about 120° F., but not higher. A good method of maintaining this temperature constant is by passing the exhaust steam from the pump around the oil supply pipe from the tank just before it reaches the pump. The method of doing this by concentric piping is shown in Fig. 31. The pipe from

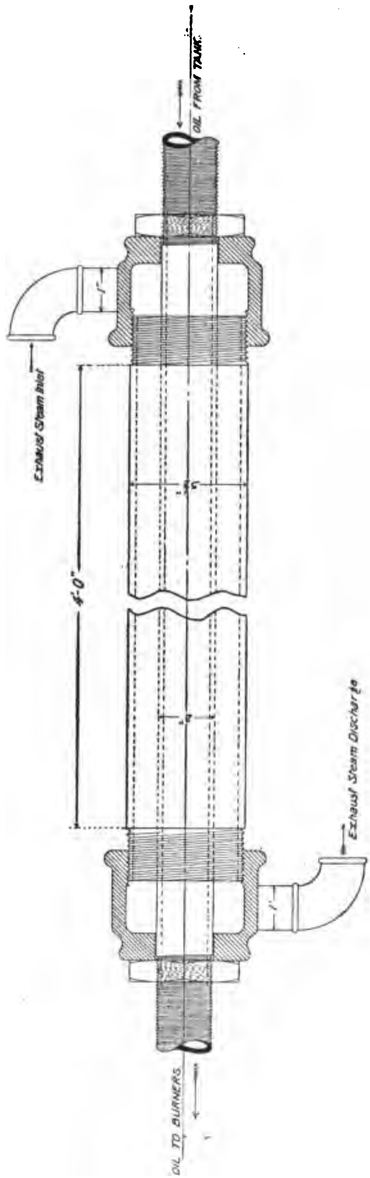


FIG. 31.—Exhaust Steam Auxiliary Heater.

the oil tank discharge valve to this supplementary heater should not be less than 2 inches in diameter.

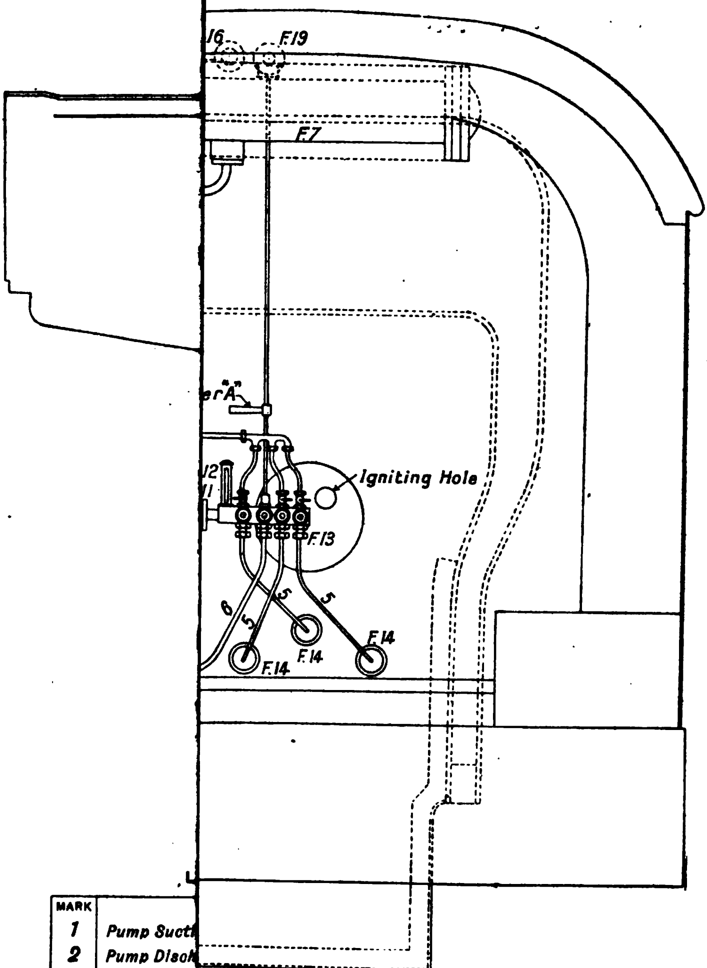
In the pressure-jet system a good deal of regulation of the quantity of oil required can be efficiently and conveniently effected by means of the pump. The pressure at which the oil is passed through the burner can be varied between 50 and 200 pounds per square inch according to the steam admitted to the pump, and this variation will be reproduced in the quantity of oil injected. The pump should be readily accessible at every point for repairing, lubricating, and cleaning. It should also be placed in such a position as not to be subject to cold draught caused by the locomotive or by wind.

The Oil Heater may be suspended from beneath the cover of the cab immediately above the locomotive regulator, especially in cold climates. If there is not sufficient room to place it in the cab, it may be placed on the foot-plate just outside, but it should then be completely enclosed in a casing packed with asbestos. This casing and packing is necessary in addition to the lagging supplied with the heater around the steam or oil portion. As the oil passes through the heater very slowly, any exposure of the heated surface causes considerable radiation. Loss of oil temperature would result if this additional protective casing and lagging were not provided.

If the heater is placed on the foot-plate it should be raised by supports about a foot in order to give access to the drain valve. Due regard must also be had for accessibility.

The Discharge Filter should be placed in a position of ready access for the removal of the filter bags for cleaning. As the heated oil must pass through the filter it should not be placed in any position subject to draughts of cold air.

Other parts of the apparatus should be so disposed as to give freedom for operation, inspection and repairs. All pipes and exposed oil or steam surfaces should be well lagged, with the following exceptions :—(*a*) the oil drain pipes from the discharge filter ; (*b*) the overflow pipe from the pressure relief valve on the pump to the suction side of the pump or oil tank ; and (*c*) the oil-circulating pipe from the control or distribu-



MARK		
1	Pump Suct	
2	Pump Disch	
3	" "	
4	" "	
5	" "	
6	Circulating	
7	Escape to S	
8	Pressure G	·to Strainer
9	Steam to In	
10	" Pu	ge to Burners
11	Exhaust fr	
12	" "	
13	Drain from	

GS

MARK No.	DESCRIPTION
F 14	Burners
F 15	Tee Piece Steam to Heater & Pump
F 16	Valve Steam to Heater
F 17	Valve Steam to Pump
F 18	Valve Exhaust from Pump
F 19	Cock Regulated Steam to Heater

tion valve box of the burners to the suction side of the pump or tank. These should be left unlagged, as the oil in returning to the pump may become too hot, and the pump will not work well with oil at a temperature over 140° F. The control or distributing valve boxes for oil supply to burners should be fixed at a height of 3 to 4 feet above the footplate in the cab and right above or at the side of the firehole. A general arrangement of all these fittings on a locomotive cab is illustrated in Fig. 32.

Other Parts of the Equipment.

The other parts of the equipment which call for some notice are the Tanks; Pipes leading from the tanks to the pump, etc.; and Firebricks.

It is obviously not possible to make any rigid regulations in these respects owing to the diversity of conditions. A few general points, however, may be observed.

Oil Tanks on Tenders.—The size and arrangement of oil tanks on tenders will of course vary according to the space at disposal. Space for space compared with coal the capacity can usually be very considerably increased, or alternatively the water space can be augmented. The calorific value of oil being about 40 per cent. higher weight for weight, and the ratios in weight of coal and oil per cubic foot being 50 pounds and 59 pounds respectively, taking the specific gravity of oil at 0·950, it follows that about 58 per cent. more fuel capacity can be secured with oil. This increase may be considerably added to by constructing the oil tank higher than would be possible to carry coal.

On some systems cylindrical oil tanks are preferred to rectangular ones, and an illustration is given in Fig. 33 of such construction in use on the San Paulo Railway, Brazil, where two tanks of the dimensions shown are placed side by side on the tender and coupled by means of a pipe beneath.

The design and dimensions of oil tanks will follow those for water, with the following modifications:—

1. *All Seams* and joints should preferably be welded by the oxy-acetylene welding process in place of riveting. A

riveted tank may be made perfectly water-tight and remain so for containing water, but when used for oil will show most incredible leakage, which is very difficult to stop by caulking or otherwise. The oxy-acetylene process absolutely ensures oil-tight joints, with the satisfaction of knowing that they will remain tight. It is not good policy to weld riveted joints, because in so doing the rivets will "spring" and leakage be inevitable.

2. *The Opening* for filling the tank should be covered by a

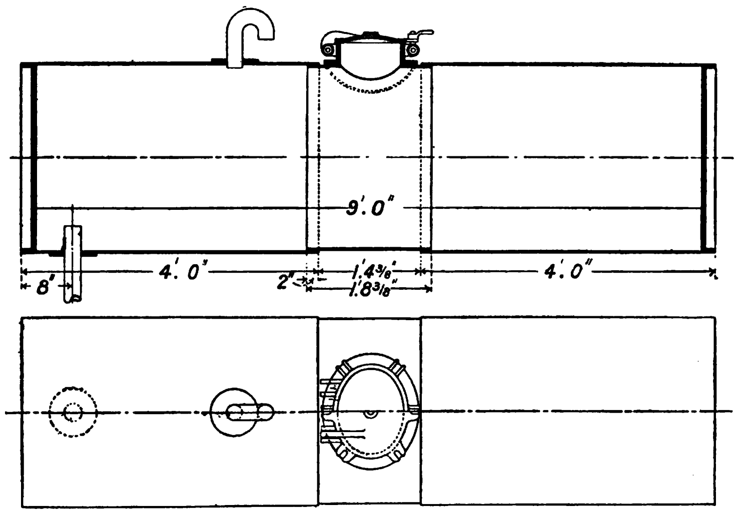


Fig. 33.—Cylindrical Oil Tank.

hinged door, mechanically fitted, and oil-tight. This should be clamped down by swing bolts having a lever nut.

3. *The Tank* should contain heating coils or convolutions of piping, of from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches diameter, for the passage of steam to heat the oil when the viscosity is too high or when the oil becomes thick in cold weather. The smaller diameter of pipe is large enough for live steam, but the larger must be used if exhaust steam from the oil pump is passed through. In the former case the rule is 1 square foot of pipe area for each ton of oil, or 2 square feet if exhaust steam is used. It is not desirable to pass exhaust steam continuously through the heating coil, and therefore this should only

form a bye-pass to the usual exhaust. In Table 13 is given the superficial area of tubes in square feet per foot run. The heating coils should be placed as near as possible, without actual contact, to the bottom of the tank.

4. *The Discharge Pipe* must not be less than 2½ inches internal diameter, and should enter the tank from 4 to 6 inches, so that any water which the oil may contain will not be drawn off with the oil. This water can be discharged by means of a small valve at the lowest point of the tank. Over this discharge pipe it is desirable that a strainer mesh plate be fitted, of sufficiently large dimension to allow of free passage of oil, with a mesh of about 1 sq. mm. holes. This plate or covering must be removable to enable it to be cleaned. Immediately beneath the point of entry of the discharge pipe a full through-way stop valve should be fitted.

TABLE 13.—SUPERFICIAL AREA OF TUBES IN SQUARE FEET PER FOOT RUN.

External Diameter.	Area in sq. ft.	External Diameter.	Area in sq. ft.	External Diameter.	Area in sq. ft.
¾	0·1962	1¾	0·4580	3¼	0·8508
⅞	0·2291	1⅞	0·4906	3½	0·9163
1	0·2618	2	0·5233	3¾	0·9817
1⅛	0·2945	2⅛	0·5562	4	1·046
1¼	0·3270	2¼	0·5890	4½	1·1781
1⅜	0·3599	2½	0·6544	5	1·309
1½	0·3927	2¾	0·7199	5½	1·44
1⅝	0·4253	3	0·7854	6	1·570

5. *A Filter*, portable and strong, as shown in Fig. 34, is necessary when filling the tank with oil, in order to collect any seriously large particles of foreign matter present in the oil. This filter is placed temporarily in the tank opening, and is provided with handles for lifting in and out. Sometimes fuel oil contains grains of sand in suspension.

6. *A Steam Connection* should be fitted to the tank or tanks for the purpose of cleaning out the oil prior to under-

taking any repairs which may be necessary. This precaution is absolutely vital in the event of any naked light or flame required inside. Every particle of oil should be steamed out and the tank remain open to the atmosphere afterwards for some time to ensure free ventilation.

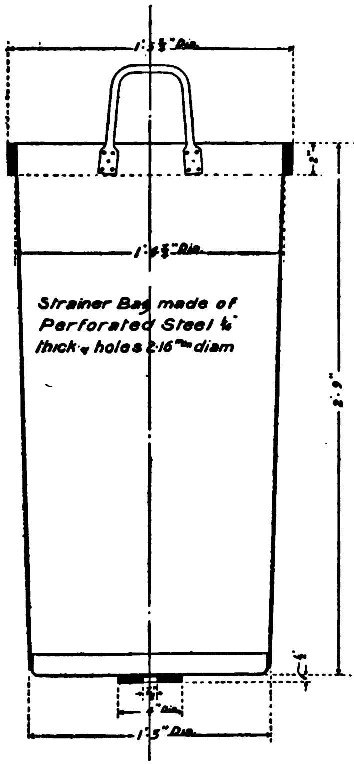


Fig. 34.—Oil Tank Filter.

7. *A General Arrangement* of a rectangular tank on a tender is shown in elevation and plan in Figs. 35 and 36, these being drawn from illustrations of the method adopted on the Mexican Railway, where steam-jet burners are used.

8. *Ventilation* of the tank should be provided for by fitting one or more 2-inch pipes on top, standing out 6 or 8 inches and bent over against the weather.

Oil Pipes.—Oil pipes which are not subject to internal pressure of oil may be of ordinary lap-welded iron, but it is better to employ only solid-drawn steel pipes for connections between the pumps, heater, filter, and distributing valves. Between the distributing valve boxes and the burners copper pipes may be used, as these are necessarily of small diameter and lend themselves to bending and adjustment. All joints in copper piping with unions, etc., to be brazed. Pipes between the tender and engine must necessarily be flexible and should be of flexible metallic hose or that known as mechanical knuckle jointing. Another type is sometimes employed, having a ball-and-socket joint at each end, with a sliding joint at the centre, and is illustrated in Fig. 37. The

ball and socket permits of up, down and lateral motion, and the sliding joint allows for the differences of distance between

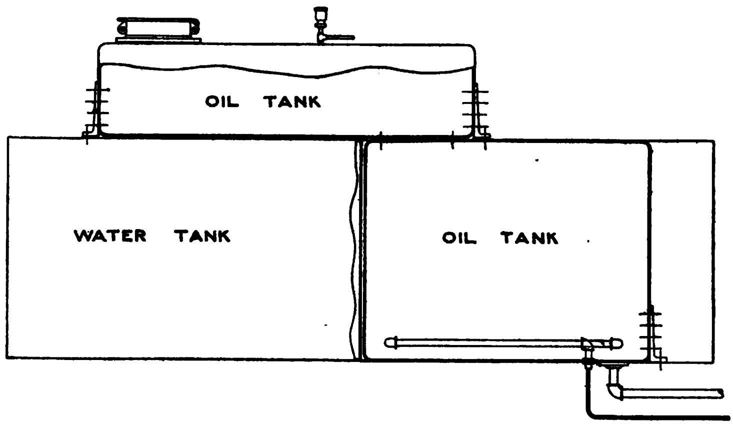


FIG. 35.—Rectangular Oil Tank (Elevation).

the engine and tender. Union nuts are provided at both ends. With this type it is necessary to use packing on the gland, and under no circumstances must indiarubber or

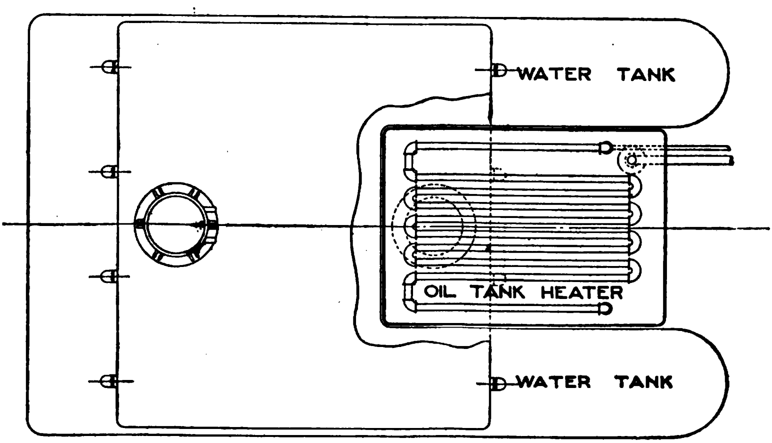


FIG. 36.—Rectangular Oil Tank (Plan).

packings containing rubber be used, as oil immediately attacks it. This type could only be used for oil flowing under gravity.

Pipe joints for oil under pressure and at a high temperature should be made with a coating on the threads of a mixture of litharge and glycerine.

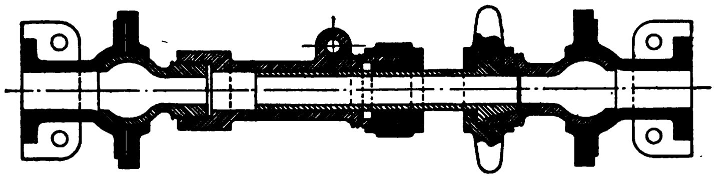


FIG. 37.—Flexible Type Oil Pipe.

The following Table 14 gives the diameter of suction and delivery pipes for different oil capacities per hour :—

TABLE 14.—SIZES OF SUCTION AND DELIVERY PIPES.

Quantity of Oil in lbs. per Hour.	Diameter in Inches.		
	Pump Suction.	Pump Delivery.	
	At Atmospheric Pressure.	At 15 lbs. per sq. in. and 100° F.	At 150 lbs. per sq. in. and at 250° F.
250	2·0	1·0	0·75
500	2·5	1·25	1·0
750	2·5	1·5	1·0
1,000	3·0	1·5	1·25
1,500	3·0	1·5	1·25
2,000	3·0	2·0	1·5

FIREBRICKS.—With oil fuel the brickwork is subject to a greater degree of impingement of the incandescent particles than in coal firing, and consequently only the best and most refractory bricks should be used. For arches and circular work shaped bricks should always be employed, as these last much longer and save their cost in lessened repairs. The minimum of fireclay or jointing cement should be employed. The chief essential, however, conducive to

lasting brickwork is to dry thoroughly the bricks before being built in. All moisture, however slight and non-apparent, should be driven out prior to use, and not in the firebox. The moisture in the porous nature of the bricks causes fractures and rapid breaking up of the best class of brickwork. Whatever may be the arrangement of brickwork within the firebox, the fire door should always be lined with firebrick. The bricks should be built in angles attached to the door so that the door can be opened freely, the brickwork lining forming an intrinsic part of the door.

An observation hole should be arranged in the door, the brickwork being left clear to suit the hole. The hole, of course, must be covered by a movable shutter on the outside of the door.

SECTION VII

TESTS AND RUNNING CONDITIONS

Making Tests and Taking Records.

Some idea will have been formed from the variety of conditions affecting the efficiency of oil-fuel installations on locomotives given in the previous sections of the absolute necessity of making reliable tests. Without some method of independent testing, in which the conditions are observable and can be recorded, it is impossible to arrive at any reliable conclusion as to the real behaviour of oil-burning apparatus. This is of course equally true of coal-burning, but so far oil has been and will continue to be a substitution for coal under modified conditions which have been carefully designed for coal burning only. The tests, therefore, of oil fuel really resolve themselves into proving how far the adaptations or modifications of coal-firing conditions are satisfactory and efficient, quite as much as, if not even more than, proving the efficiency of the apparatus or system employed. This will remain the position until locomotive engine builders recognise the importance of designing oil-burning locomotives, a *desideratum* which the author would like to see brought about in the near future.

Locomotive fuel tests are of two classes, viz. :—

(1) Evaporative Efficiency of Boiler ; and (2) Tests under Running Conditions. The first concerns itself with the quantity of water evaporated from and at 212° F. per pound of oil at different rates of oil supply per hour. It is carried out while the engine is at rest by means of draught created by auxiliary steam in the usual way, and it includes the relationship between all parts from the dampers to the chimney. The second test involves the efficiency of the cylinders and the rest of the machinery, together with conditions of weather, track, load, handling, and such like.

This is the "practical result" test, and it is expressed in terms of "oil per train mile," "oil per ton mile," "oil per tens of tons per mile," etc., and includes all oil used from start to finish, whether standing or running. It is evident, therefore, that, as these external conditions must differ greatly from day to day, and their effect may thus be favourable or adverse, the value of such records is only reliable when averaged over a considerable period. The minimum period should be a month of daily runs.

The object of all tests is to investigate every condition which affects efficiency, in order that those parts which are capable of modification may be adjusted accordingly to approach as nearly as possible to theoretical requirements. It is obvious, therefore, that such details should be adjusted under artificial conditions when the engine is at rest, and that the locomotive should not be put under a running trial until the general behaviour of the whole installation is known. Subsequent necessary adjustments will thus be readily determined and effected.

In this connection it may be observed that one of the "external adjustments" is the manner in which the firemen handle the apparatus. The relation between firing and the admission of feed water, for instance, is all-important from the economical point of view, and this is essentially a matter of good training, experience, and intelligence.

In this second series of tests—the pounds, shillings, and pence factor—comparisons are made with results previously obtained with coal firing, as these involve all the ordinary running conditions. With efficient combustion and proper handling oil fuel should show much higher evaporative results than with coal for the reasons given in Section I. under "Advantages of Oil Fuel," but these will only be obtained after it is ascertained that the installation is efficient at all loads under evaporative trials.

Evaporation Test.—This should be conducted in a similar manner to testing stationary boilers. The draught is created by the blower, the steam for which must be taken from another engine or from some external source. The steam raised in the boiler must escape freely into the atmo-

sphere, and if necessary the dome should be removed for this purpose.

The principal observations to be taken are :—

1. Accurate measurement of oil used.

2. Accurate measurement of water supplied to boiler and actually evaporated.

3. Temperature of the feed water.

4. Temperature of gases in smokebox.

5. Temperature of furnace (if possible).

6. Frequent records of percentage of CO_2 from smokebox.

7. Degree of draught in inches of water.

8. Calorific value of the fuel.

These tests should be applied under steady evaporation for two hours at maximum oil supply as calculated theoretically, and again for two hours with half the maximum quantity of oil. The position of all parts should be noted and any necessary adjustments made. The records and measurements should start and finish when full evaporation is occurring only, and should take no account of the preliminaries.

The deductions from the foregoing observations will follow the lines already fully described herein. There are very reliable appliances on the market for obtaining high temperature records.

Running Trials.—The following Table 15 gives a form of recording the necessary details over a series of running trials, in order that comparisons with coal or other fuel or one system of oil burning with that of another may be made :—

TABLE 15.—LOCOMOTIVE DEPARTMENT.

Class of Fuel......	System	Date ....
Train No.	From...........	To ....
Driver	Fireman	

Stations.	Miles between Stations.	Running Time.	Stand-ing Time.	Shunt-ing Time.	Oil in Tank.	Water in Tank.	Fuel used in lbs. per Mile.

Train weight in decatons ....
Train mileage ....
Train in axles........................
Light engine mileage.................
State of weather ....
Condition of rails.....................
Observations.........................

Running Conditions.

Steam-Jet and Pressure-Jet Systems.

The modern locomotive, being the result of long years of experience and careful observation, is designed accordingly; and the charge of being a bad "steamer" can hardly be attributed to design. Still, it is a well-known fact that "sister" engines built from the same designs vary to a great degree in their steaming capacity, and in this case design may be very properly saddled with the fault.

Apart, however, from design, there are admittedly three causes of a poor steaming engine—(1) improper or insufficient draught; (2) the heat not being fully utilised; and (3) mismanagement on the part of the enginemen. However, dealing with oil fuel as against coal, cause No. 1 may be safely dismissed, as there will be no cinders to fill and stop up the tubes, and, as dealt with elsewhere, the smokebox and vacuum-creating appliances generally will be under special observation with a view to fulfilling the new fuel conditions.

Cause No. 2 can be traced to poor water circulation, dirty boiler, etc., etc., and, although it need not be reviewed here, an observant engineman can help his record much by giving strict attention to the state of the boilers.

Treating cause No. 3 and its eliminations, it may be useful to note initially that, with coal firing, nearly every engineman or fireman has a different conception of how a given engine ought to be fired. With oil fuel the conditions of firing are very different, as it is not entirely left to the intelligence of the engine staff, nor to the capacity of the fireman as such, to keep the fire fed as it should be. On the contrary, with the burners placed as they ought to be, the proper distribution of the fuel takes place automatically.

This should place the fireman in a better position than ever to make the two chief features of his work harmonise—viz., the firing and feeding of the boiler ; and as the essential points between oil and coal firing are identical on the firing and feeding of a boiler, a few remarks here may be useful.

Knowing the Road.—In the first place, the engine staff should know the road thoroughly. A fireman, with an intelligent conception of his work and knowing the road, can anticipate every move on the driver's part. He will have the necessary burners going for a hard pull on the up grade, as well as knowing when and where the injector can be shut off, and a burner cut out, without impairing the efficiency of the engine in any way. This makes for economy.

Again, on the other hand, however capable a fireman may be, or inclined to study the economical working of his engine, all his efforts in that direction may be completely nullified if a driver does not recognise and act up to his fireman's efforts in that direction. It has been well said that a fireman " may save by the ounce while the driver wastes by the pound."

Water in Boiler.—A proper knowledge of the road is all-important in the consideration of maintaining the necessary water in the boiler. It is obvious that if the boiler is full of water (up to the point that there is no danger of priming) and it is a hard up grade that has to be negotiated the water will not require so much from the fire. Not only is this so when actually working on the grade, but it applies also to the quality of water that may be in the boiler at the moment of drawing out from a station. A case in point which came under the writer's observation can be given.

It was with a test load. The train had stopped to take water at X. before beginning a long up-hill pull of fifty miles. The enginemen, knowing the road as they must have known it, ought to have left X. with the boiler in that condition, as far as water was concerned, so that they could have worked the train up to the maximum speed without having had recourse to the injectors. But the very reverse was the case. The engine left X. with about 1½ inches of water in the boiler, and before any speed was reached at all, and the engine working at a long cut-off and using much steam, the injector had to be put on. The result was that they were practically "burning the candle at both ends," as whilst the engine was using the greatest volume of steam, the injector was pouring cold water into the boiler. With a start like that they were practically in "Coventry" all the way up to the top, which naturally told on the consumption of fuel, reaching the summit with an excess of 5 pounds of fuel per mile. Two days later the trip was repeated in much the same conditions, but with different results, as at the writer's suggestion the fault, as regards amount of water in the boiler, was remedied.

Regulation and Care of Oil Pump.—It should be the care of the engineman to see that the pump is kept in good condition. It goes without saying that the pump is really the "heart" of his engine. That being so, it is highly essential that the engineman should thoroughly understand the component parts of it, so that under the least necessity he would be able to remedy a defect. Just as in the case of the piston and valve glands of his engine, the engineman should take every care of the pump glands. Sometimes the pump will work in an irregular and jerky manner, which is detrimental to the steady supply of the fuel to the firebox, and may thus diminish the steaming power of the boiler. The writer has seen enginemen resort to striking the pump with a hammer or key, thinking to "liven" it up in that way, whereas, on examination, the gland packing was found to be dry and hard and acting as a brake on the movement of the piston.

In the regulation of the pump on the road it is obvious that

a thorough knowledge of the road is absolutely necessary. As the supply of oil to the firebox is sometimes controlled by the action of the pump, and not by the oil-way cocks on the front, it may be necessary from time to time (according to the number of burners in action) to increase or decrease the flow of steam to the pump. This is really as it ought to be, and should be attended to, but in many cases it is overdone. To take a case in point. An engine, for example, is working a train up an incline. The engine is not being "punished," but working fairly hard, and the injector is gaining on the consumption of water. This will necessitate shutting off the injector, but before this is done the pressure is allowed to come down 5 to 10 pounds. Instead of allowing the pressure to come back gradually, immediately the injector is shut off, more steam is put on to the pump to make it inject more oil into the firebox, and in another minute the boiler will be "blowing off" and the pump will have to be shut off again. A little thought would make the fireman see that even if the oil-pressure gauge did register a little less pressure the pump would gradually return to its former rate, consistent with the gradual increase of steam in the boiler.

Draught Appliances.—Although it has been said elsewhere in this work that "draught-creating appliances would be under special observation," it has also been said that "sister engines differ in their steaming capacities." This would mean that, even after the most careful adjustment of the existing draught appliances, an engineman, by careful observation, might be able to materially improve the steaming capacity of the engine under his control. If not effecting the change personally, the following remarks on the two most common appliances would enable the driver to put in his report on the needed changes in an intelligent manner.

Petticoat Pipe.—The function of this pipe is to equalise the draught through *all* the tubes. It is generally made telescopic, so that its top part can be lowered or raised without interfering in any way with the position of the bottom part. Now if, in the carefully-weighed opinion of the engineman, there is too much draught in the upper tubes, the top part of

the petticoat should be raised sufficiently to regulate it. If, on the other hand, there are indications of too much draught in the lower tubes, the lowering of the top part should give the necessary adjustment. It should also be noted that, as far as draught is concerned, the top tubes dominate the part of the firebox at the back end, whilst the bottom tubes have their effect on the front, or tube plate, end. In moving the top part of the petticoat pipe much care must be taken in conserving its proper alignment with the chimney.

Deflector Plate.—This plate is fixed to the top of the tube plate in the smokebox, and extends right across the face of the tube plate, sloping gradually outwards towards the exhaust pipe. The bottom part of this plate is made adjustable, having elongated holes, which permits it to be lowered or raised as the case may be, it being kept in position by bolts. The deflector plate serves the double purpose of deflecting cinders, etc., to the bottom of the smokebox, and also as a draught equaliser. However, it is only the latter function that has to be considered here.

If it is found that there is too much draught through the upper tubes, the movable part of the plate should be lowered, thus choking the draught through the upper tubes. Again, if it be the lower tubes that have too much draught, this can be counteracted and the draught equalised through the tubes by raising sufficiently the lower part of the deflector plate.

THE BLOWER.—The blower is really one of the most useful aids a fireman can have, but it is also common knowledge that it is grievously misused. With the introduction of the firebrick arch additional care had to be taken in the use of the blower, owing to the greatly increased temperature of the firebox, especially when a fire had been drawn. With the advent of oil fuel, and the consequent use of a more extensive brick lining besides the arch, the use of the blower should be more judicious than ever, as, even with the burners extinguished for a considerable time, the brick lining and arch will maintain a high temperature and an intense white heat in the firebox.

INSTRUCTIONS TO ENGINEMEN.

Starting Up.

STEAM-JET SYSTEM.

1. Open steam to heating coils in oil tank.
2. Open steam to burner before opening oil valve.
3. Open oil valves and light up.
4. Adjust air admission, oil, and steam until smoke almost disappears. If auxiliary steam is used, that is, steam from another locomotive, the quantity of oil admitted must be regulated in accordance with the vacuum produced in the firebox. Steam should always be *dry* and at the pressure used under running conditions.
5. Use no more steam than is absolutely necessary to atomise the oil.
6. Allow a good draught of air through firebox before lighting up.
7. Steam pressure should be raised slowly.

PRESSURE-JET SYSTEM.

1. Open valve on oil tank and oil valve on pump suction side.
2. Open inlet and outlet valves on one side of the duplex filter.
3. See that the burner valves are closed.
4. Open the steam valves to heater and start the pump.
5. Open the oil circulation valve.
6. Circulate oil until a temperature of about 150° to 200° F. is reached.
7. Close the oil circulation valve and raise the oil pressure to 90 pounds.
8. Light a handful of cotton waste soaked in kerosene and throw it into the firebox. Then open one of the oil burner valves and light up.
9. Regulate damper and draught to give combustion with the merest trace of smoke from the funnel, and regulate oil supply.

10. Raise oil pressure to 150 pounds.

11. Where no steam is available a hand pump and special heater should be provided.

12. Under no circumstances when starting up should the oil be admitted to the burners until the lighted cotton waste is burning freely inside the firebox.

13. The temperature of the oil should be about 270° F.

14. Allow a good draught of air through firebox when lighting up.

15. The full steam pressure must be maintained in the heater and no water allowed to accumulate.

Running.

STEAM-JET SYSTEM.

1. Never force the firing with oil fuel, or the flame will have the effect of a blast-jet, with liability to burn the shell and rivet heads and cause unequal expansion and leakage of tubes.

2. Oil firing should never cease while engine is running, unless a cap is employed to cover the funnel.

3. Opportunity should be taken of working feed water injector or pump when standing at stations or on sidings.

4. The oil in the tanks should be heated, but steam should not be kept on continuously. Oil retains its heat for a long time, and once heated the quantity withdrawn for the burners will cover a considerable period. The heating of the oil can be done while the engine is standing.

5. Sand blast should be used occasionally with proper direction towards smoke tubes.

6. At finish of journey oil valves must be closed before the steam valves of the burner in order to allow all oil in pipes to burners to be cleared to prevent carbonisation of oil in burner.

7. No naked lights or lantern of any description must be taken near to the oil-tank-filling hole when open, or near the tank at all at any time, as explosive vapours escape from ventilation pipes.

Pressure-Jet System.

1. Whenever it is necessary to close down a burner, the steam blow-through cock should be opened and steam allowed to pass until oil is again required.

2. Watch the pump lubrication and see that the drain cock from the heater is passing steam with the condensed water. This cock should drain the water from the heater without lowering the steam pressure therein or blowing through steam to waste.

3. Clean out the oil filters at regular intervals, always having one side ready for use.

4. If coking should occur inside the firebox, remove the deposit by a bar at the first opportunity. Coking is a result of imperfect combustion, usually due to an excess of oil or improper fixing of the burners.

5. When the locomotive has finished duty, all valves should be closed. The air dampers should be a tight fit when closed. A plate should be put on the top of the funnel.

6. Keep every part scrupulously clean and in first-rate working condition.

Specification Clauses for Locomotive Oil-Burning Equipment.

There is nothing more unsatisfactory for both the seller and the purchaser than a want of knowledge on both sides of the conditions existing and to be fulfilled. It is too often the custom for the purchaser to assume that the seller knows or ought to know all about the requirements affecting a particular inquiry for which a tender is desired, no matter whether the article or apparatus is to be used in some remote country. The purchaser often resents the request for plans and further necessary information, while the seller on his part is frequently guilty of selling goods which he knows cannot fulfil the expectations of the purchaser. In some cases the purchaser lays down obligations altogether too onerous, and equally the seller may offer apparatus unnecessarily expensive and elaborate. This state of affairs is

more likely to happen where the article required is not of a standardised character, or in those cases in which the conditions are largely indeterminate. Oil-burning equipments come under these definitions at present, and the following clauses are therefore submitted with the view of meeting the case as far as possible.

It must be understood that nothing in the nature of general or legal conditions have been embodied, as such, together with terms of payment, deliveries, and unfulfilled contract, etc., are outside the sphere of technicalities.

Specification Clauses.

To be embodied, with necessary modifications, with the usual Contract Conditions and Forms of Tender. The word "Purchasers" means the railway or other company asking for the Tender, and the word "Contractor" means the supplier of the oil-burning apparatus.

1. *Apparatus Required.*—The Purchasers require ...... oil burning installations of the steam-jet (pressure-jet) type, complete with all accessories between the oil tank and the burners or atomisers, for the following locomotives :—

Locomotive No.......	Type......
Locomotive No.......	Type......
Locomotive No.......	Type......

etc., etc.

2. *Accessories to be Included.*—The accessories shall include amply sufficient lengths of all the oil pipes between the several parts of the apparatus to allow for cutting, bending, etc., all unions, flanges, couplings, valves, pressure gauges, thermometers, flexible tubes, jointing material, and sundries (with the exception only of steam piping) necessary to enable the Purchasers to erect completely the installation on each locomotive.

3. *Spare Parts.*—The Tender to include a sufficient number of spares of all parts which are liable to renewal from time to time and to the extent to which the Contractor considers necessary.

4. *Parts Provided by Purchasers.*—The Purchasers will provide the oil tank on the tender ; oil tank filters ; oil tank heating coils ; oil tank discharge pipe and valve ; steam pipe connections ; firebox brickwork ; ferrules ; and any alterations specified and required by the Contractor to the firebox, smokebox, fittings, etc.

5. *Information Supplied to Contractor.*—The following information is attached hereto :—

(*a*) Drawings of each of the several types of locomotives, showing space available on tender for oil tank, etc., existing fittings in cab, and smokebox arrangement (including superheaters, if any).

(*b*) Drawing showing longitudinal and cross-sections of firebox, ashpan, etc.

(*c*) Steam pressures of each locomotive.

(*d*) Heating surface in square feet.

(*e*) Maximum evaporation required in pounds of water per hour from and at 212° F.

(*f*) Temperature of feed water.

(*g*) Analysis, viscosity, specific gravity, calorific value and flash point of fuel oil proposed to be used, and with which tests will be made.

6. *Information Required with Tender.*—The Contractor shall submit the following information with his Tender :—

(*a*) A diagrammatic drawing showing the general arrangement and connections of the several parts of the apparatus.

(*b*) A drawing or drawings of the fireboxes showing the brickwork arrangement required, positions of burners, etc., with dimensions put in and to a scale sufficiently large to form a working drawing. Details necessary, to be shown separately on the same drawings but to an enlarged scale.

(*c*) Drawing in section or otherwise of the type of burner or atomiser to be used with the system.

(*d*) Description of the entire system, its method of operation, means of regulating oil supply, method of regulating air draught, whether oil flows to pump or

burner by gravity or otherwise, and explanatory references to drawings.

(*e*) Quantity of steam used per hour for atomisation or for pump and heater.

(*f*) Pounds of water evaporated per pound of oil fuel.

(*g*) Schedules of every item included in Tender, number of each per locomotive, and material of which each item is made.

(*N.B.*—Drawings are not required showing the installation *in situ*, except as regards burners and firebox arrangements.)

7. *Material.*—The following conditions must be observed with regard to material used :—

Cast iron must not be employed for any part subject to internal pressure.

Oil pipes under heat or pressure must be of solid drawn steel tested to 1,000 pounds per square inch.

Valves used for oil at a temperature below 150° F. must be of the " straight-through " type.

No indiarubber or indiarubber compounds are to be employed either for joints or packing.

8. *Lighting-up or Raising Steam.*—It is desirable that steam may be raised in the boiler from cold water by means of the oil fuel only, when neither coal, wood or other auxiliary fuel, nor steam from outside sources is available. The Contractor must state in his Tender how this can be accomplished with the system of oil burning he proposes.

9. *Tests.*—Final acceptance of the Apparatus will only be made on the following tests being satisfactorily complied with :—

1. Evaporative test of boiler, for determining the quantity of water evaporated from and at 212° F. per pound of fuel; this test will be applied with steam escaping to the atmosphere, auxiliary steam being used for pumps, atomisers, blower, heating coils, etc. Accurate records will be taken over (*a*) full evaporation, (*b*) half evaporation, for two hours each, of oil used, water evaporated, temperature of gases in smokebox, percentage of CO_2 in smokebox, etc.

2. General running test over ...... days, under ordinary traffic conditions, with varying loads behind the locomotive, in order to ascertain the fuel consumed per ton mile.

Test No. 2 is conditional on Test No. 1 being satisfactory, and the Contractor or his duly authorised representative may attend the tests and approve the conditions or suggest any modifications he may reasonably desire to have made. Comparisons of averaged results will be made with those already obtained with the same locomotive when working with coal as fuel.

SECTION VIII

AUXILIARY APPLIANCES

Holden's Injector and Steam Fitting for Locomotives.

The illustration in Fig. 38 shows enlarged views of Holden's Patent Liquid-Fuel Injector-Ejector, with supplementary feed for locomotives. This injector requires the oil to be fed by gravity.

The injector A is shown placed in position at the aperture formed by the insertion of a copper tube and iron ferrule through the water space of the firebox.

The fuel is first admitted through the injectors by slightly raising the valves, then should a further supply be required it is obtained by opening the valves fully and so admitting the supplementary feed, the further quantity of oil being injected without any extra steam being required.

The ejector A^2 is intended to be connected up to the train pipe where the vacuum brake is used, when it will maintain the required vacuum for working the brake, and dispenses with the need of a small ejector, generally used for this purpose, or it can be connected to an arrangement of heaters in the smokebox, whereby heated air is introduced through the injectors to the firebox.

By unscrewing the large nut at the back of the injector the cones can be removed for examination and replaced without disconnecting the steam and fuel pipes.

The steam fitting C is placed in any convenient position on the boiler front to supply dry steam to the injectors. The cock C^1 is for controlling the steam to the internal annular jets of the injector. Cock C^2 is for steam to the ring on same. Cock C^3 is for blowing steam through liquid fuel pipes, valves, or injectors should they at any time become choked,

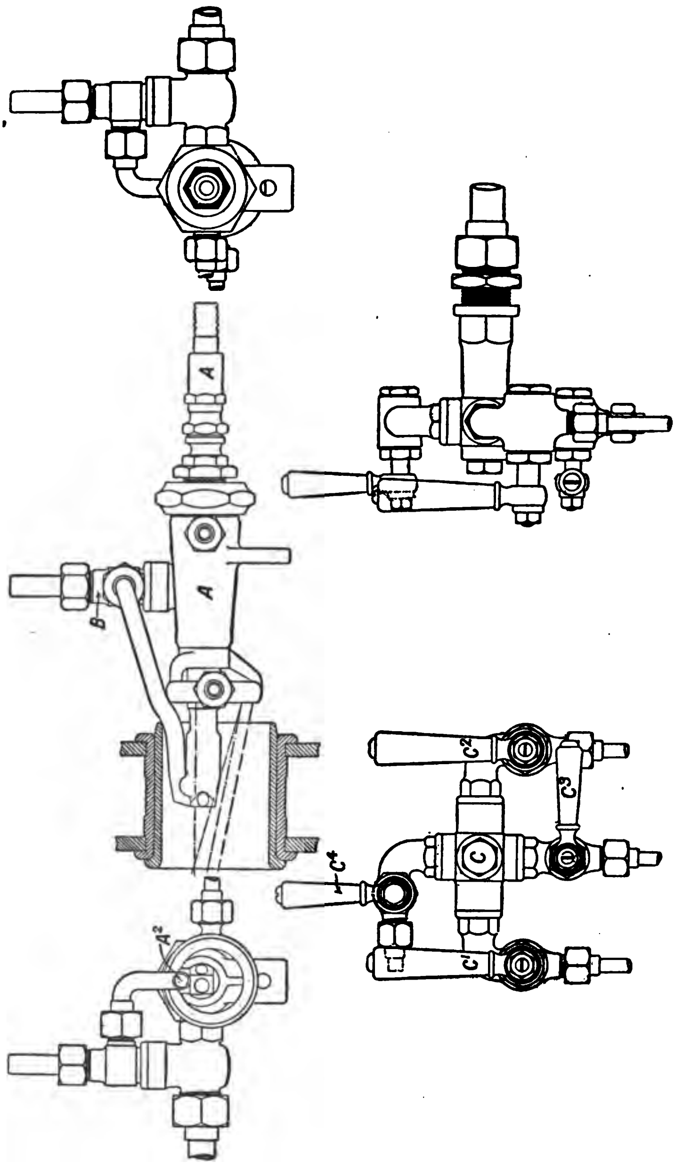


FIG. 38.—Holden's Liquid-Fuel Injector and Steam Fitting.

and the cock C^4 is for steam to a heater coil, which is placed near the fuel outlet in tank to prevent the fuel becoming thick in cold weather. These cocks are arranged for $\frac{1}{2}$ inch outside diameter steam pipe.

The Meyer-Smith Lighting-up or Starting Heater.

Fig. 39 shows the Meyer-Smith patent Lighting-up Heater, which enables steam to be raised on cold boilers without the use of coal, wood, or shore steam. This appa-

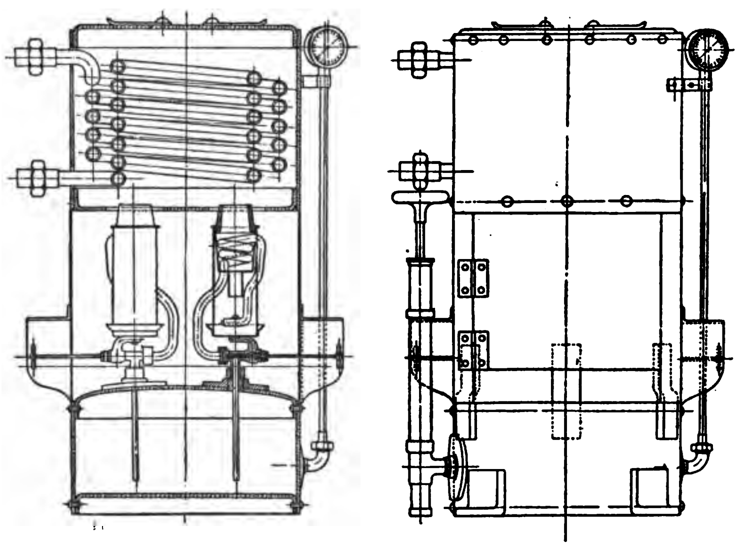


Fig. 39.—Meyer-Smith Lighting-up Heater.

ratus consists of a strong steel paraffin reservoir, fitted with the necessary pressure pump, pressure gauge, and escape connections. In the dome of this reservoir two special type self-heated paraffin burners are fixed to supply the necessary heat. Mounted on top of this tank is the oil-fuel heater or coil, which is contained in a steel chamber, lined out with fire-resisting material. The heater or coil is provided with the necessary inlet and outlet branches for the oil fuel. The inlet and outlet branches are connected to the main oil-fuel supply pipe line to the boilers and put out of action by means

I 2

of a change cock and shut-off valve, which obviates the breaking of any joints.

When using this heater for lighting-up the necessary pressure on the oil fuel is raised by means of a special type hand pump, or, if desired, a hand lever may be attached to one of the steam pumps instead.

The Thermoscope.

The Thermoscope is an instrument designed to take advantage of the simple fact that when CO_2, either pure or mixed with air, is brought into contact with caustic soda a chemical reaction occurs in which heat is generated, the amount being strictly proportional to the quantity of CO_2. It consists of an arrangement for passing a known quantity of the gas mixture through pulverised caustic soda contained in a cartridge, and for ascertaining the amount of the resulting heat by causing the cartridge to be jacketed by a special thermometer.

Description of the Thermoscope.

The instrument consists of the following main parts :—

1. A cylinder fitted with a plunger for drawing the gas mixture to be analysed from the flue, etc., and subsequently passing it through.
2. A small cartridge-shaped receptacle containing granular caustic alkali, and in which the heat reaction occurs.
3. A special thermometer with its bulb constructed to surround or jacket the cartridge so that the heat of reaction can be imparted to the mercury, the amount of its expansion, *i.e.*, the percentage of CO_2, to be observed on a movable scale.

Upon reference to the illustration, Fig. 40, the construction will be readily understood. *A* is a cylinder fitted with a piston and cup leathers and provided with a three-way tap *I* at its end.

The thermometer *B* is conveniently mounted on the cylinder *A*, and the whole is enclosed by the cylindrical jacket *C*,

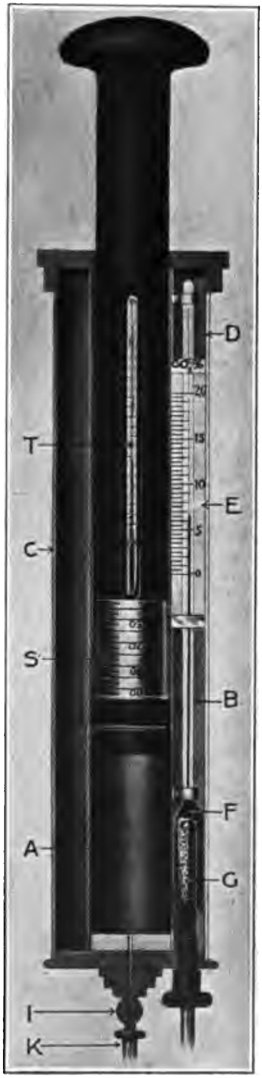


FIG. 40.

The Thermoscope.

(By the courtesy of the Underfeed Stoker Co., Ltd.)

which is slotted at *D* to show the thermometer stem. A movable scale *E* calibrated in percentages of CO_2 by volume is arranged to slide in the slot.

The thermometer bulb *F* is blown so as to form a cylindrical jacket in which is inserted the cartridge *G*. This contains the caustic alkali in the form of a dry granular powder, and when about to be used the cartridge is pricked at each end by means of a needle mounted in a cavity in the end of the piston rod in order that the gas under examination may flow through. *K* is a rubber tube connector for delivering the gas from the cylinder *A* to the interior of the cartridge.

In order to correct the volume of the gas drawn into the cylinder for varying room temperatures the length of the piston stroke when taking the sample is regulated by withdrawing to a temperature scale *S* on the piston-rod, the room temperature being read for convenience on the thermometer *T*, which is placed in a cavity of the piston-rod, or by any thermometer in the room.

The "Premier" Steam Trap.

This trap will work at any pressure and in any position. It cannot stick or fail to act. It will force the water and air

Fig. 41.—"Premier" Steam Trap.
(*By the courtesy of the United States Metallic Packing Co., Ltd.*)

1 foot vertical head for each pound of steam. It works straight through and has no side discharge.

The "Premier" trap is so regulated that *at starting the valve is wide open*, and does not close until all the air and water are blown out, and until the steam itself actually arrives. The

trap being connected by the inlet to the pipe or apparatus to be drained at the spot where the condensation water accumulates, the valve will allow the water to flow out, even up to a temperature of 211° F., but *precisely at* 212° *F.*, or, in other words, *at the temperature at which steam appears* it has expanded its entire distance, and is completely shut. The moment condensation is set up, in however small a

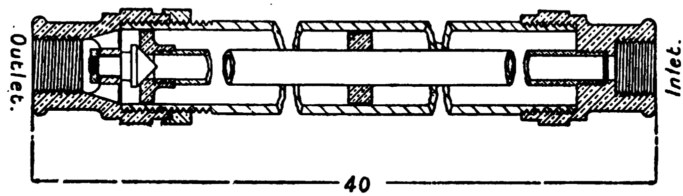


FIG. 42.—" Premier " Steam Trap (Section).
(*By the courtesy of the United States Metallic Packing Co., Ltd.*)

quantity, the temperature drops below 212° F., the valve accordingly opens, and the condensation water is blown out.

The trap is well adapted to draining water from oil heaters used with the pressure-jet system, as by its use the steam pressure is fully maintained and perfect drainage ensured. It is illustrated in Figs. 41 and 42.

TABLE 16.—CAPACITY OF " PREMIER " STEAM TRAPS.

Trap No.	Diameter of Connecting Pipes.	Water expelled per Minute (approximately) under Normal Conditions.	Water expelled per Minute (approximately) at Starting, when Cold.	Approximate Length of Steam Pipe 6 inches in diameter, or its equivalent, that the Trap is able to Drain.
	Inches.	Gallons.	Gallons.	Feet.
1	$\frac{1}{2}$	$\frac{1}{4}$	$2\frac{1}{2}$	30
2	$\frac{3}{4}$	$\frac{1}{2}$	$5\frac{1}{2}$	80
3	1	$\frac{3}{4}$	9	130
4	$1\frac{1}{4}$	1	12	180
5	$1\frac{1}{2}$	$1\frac{1}{4}$	20	300
6	2	$2\frac{1}{4}$	45	650

It is made by the United States Metallic Packing Company, Ltd., Bradford, Yorkshire.

TABLE 17.—CONVERSION TABLE.

To convert	Multiply by
Kilometres to miles	0·62
Kilometres to yards	1093·60
Metres to yards	1·10
Metres to feet	3·30
Centimetres to inches	0·3937
Millimetres to inches	0·039
Miles to kilometres	1·60
Miles to metres	1609·31
Yards to kilometres	0·0009
Yards to metres	0·914
Feet to metres	0·305
Inches to centimetres	2·54
Inches to millimetres	25·4
Square metres to square yards	1·2
Square metres to square feet	10·76
Square centimetres to square inches	0·155
Square millimetres to square inches	0·0015
Square yards to square metres	0·836
Square feet to square metres	0·093
Square inches to square centimetres	6·451
Square inches to square millimetres	645·10
Cubic metres to cubic yards	1·3
Cubic metres to cubic feet	35·32
Cubic centimetres to cubic inches	0·061
Cubic yards to cubic metres	0·764
Cubic feet to cubic metres	0·028
Cubic inches to cubic centimetres	16·386
Kilogrammes to tons	0·001
Kilogrammes to cwt.	0·02
Kilogrammes to pounds	2·2
Kilogrammes to ounces	35·3
Tons to kilogrammes	1016·0
Cwts. to kilogrammes	50·8
Pounds to kilogrammes	0·454
Gallons to cubic feet	0·16
Gallons to cubic metres	0·0045
Gallons to litres	4·5
Gallons of water to pounds	10·0
Cubic feet to gallons	6·24
Cubic metres to gallons	220·0
Litres to gallons	0·22
Pounds of water to gallons	0·10
Litres to cubic feet	0·035
Litres of water to pounds	2·2
Cubic feet to litres	28·32
Pounds of water to litres	0·454
Cubic feet of water to pounds	62·27
Pounds of water to cubic feet	0·016
Feet per minute to miles per hour	0·0113
Feet per minute to metres per second	0·005
Miles per hour to feet per minute	88·0
Metres per second to feet per minute	197·0
Tons per square foot to pounds per square inch	15·5
Kilogrammes per square centimetre to pounds per square inch	14·2
Atmospheres to pounds per square inch	14·7
Atmospheres to kilogrammes per square centimetre	1·0335

CONVERSION TABLE—*continued.*

To convert	Multiply by
British thermal units to foot-pounds	778·0
Calories to metre-kilogrammes	426·84
Foot-pounds to metre-kilogrammes	0·1382
Metre-kilogrammes to foot-pounds	7·231
Degrees F. to degrees C.	$\left(\frac{5}{9} - 17{\cdot}7\right)$
Degrees C. to degrees F.	$\left(\frac{9}{5} + 32\right)$
British thermal units to calories	0·252
British thermal units per pound to calories per kilogramme	0·554
Calories per kilogramme to British thermal units per pound	1·8
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THE present book will it is hoped be of assistance to the practical worker as well as to the student of oils and fats. It has been the out-growth of a number of years of observation and experience involving the collection of a considerable amount of data from many sources.

Heretofore, the literature on hydrogenation has been scattered through many periodicals, and no effort has been made to collect this material and arrange it in book form, although the treatises of Hefter and Ubbelohde and Goldschmidt include a few pages on the conversion of soft fats by various methods to stearic acid or stearin; but such reviews have been too brief to afford the practical operator sufficient working material.

A considerable mass of data, including practically all that has been advanced on the subject of hydrogenation of fatty oils, has been collected and arranged in this volume. The observations and opinions of many minds have been brought together. Some of these views obviously are sound, others are open to grave doubt, and still others are of a contradictory or polemical nature. Whether or not in the treatment of this material to carry through a vein of critical comment was a problem which confronted the author, and the conclusion was reached that at this stage of a young art, it would be inadvisable in general to do more than array the multitude of processes, formulæ, proposals, and opinions, leaving to the reader the selection of that which would prove of greatest utility.

A few years hence, when oil hydrogenation will have found its measure, and the more important points concerning it have reached definite settlement, the allotment of space to a number of the discussions appearing on the following pages would hardly be warranted, but at the present time, when many are desirous of having at hand a treatise which comprises all or nearly all the published work to date, containing though it does a considerable divergency of opinion, there appears ample justification for the inclusion of material which later may be considered superfluous.

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